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AN INVESTIGATION OF METHODS TO MEASURE AND PREDICT BIOLOGICAL AND PHYSICAL EFFECTS OF COMMERCIAL NAVIGATION TRAFFIC: WORKSHOP II

by

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13. ABSTRACT *(Maximum 200 words)*

On 17-18 April 1990, a workshop on commercial navigation traffic was held at the Holiday Inn, Riverfront, in St. Louis, MO. The purpose was to investigate strategies for measuring and predicting physical and biological effects of commercial traffic in inland waterways. The meeting was attended by personnel from the US Army Engineer Waterways Experiment Station, Headquarters, US Army Corps of Engineers (HQUSACE), USACE District and Division Offices, the Institute for Water Resources, the US Fish and Wildlife Service (USFWS), the Tennessee Valley Authority, and State Agencies.

The workshop was divided into three sections. Sections I and II dealt with physical and biological techniques, respectively, to measure and predict the effects of commercial navigation traffic. Each section was divided into discussions of laboratory studies, field studies, and predictive models. Section III consisted of presentations that dealt with techniques and approaches that have been used by Districts and the USFWS for analyzing and predicting commercial traffic effects.

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PREFACE

In October 1985, the US Army Engineer Waterways Experiment Station (WES) initiated a multi-year study on the environmental effects of commercial navigation traffic in large waterways. This work is part of the Environmental Impact Research Program (EIRP) at WES. In April 1990, a workshop was held in St. Louis, MO, to investigate strategies to measure and predict physical and biological effects of commercial navigation traffic. The workshop was attended by planners, engineers, and biologists from Corps District and Division Offices, Headquarters, US Army Corps of Engineers, the US Fish and Wildlife Service, the Tennessee Valley Authority, and two State agencies. This report contains papers presented by attendees and a summary of major findings of the workshop.

The report was edited by Ms. Janean Shirley of the WES Visual Production Center, Information Technical Laboratory. Mr. Edwin A. Theriot was Chief, Aquatic Habitat Group, Environmental Laboratory (EL), WES; Dr. Conrad J. Kirby was Chief, Environmental Resources Division, EL; Dr. John Harrison was Chief, EL; and Dr. Roger Saucier was Program Manager of the EIRP during the preparation of this report.

Commander and Director of WES was COL Larry B. Fulton, EN. Technical Director was Dr. Robert W. Whalin.

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* Papers in this document are based upon oral presentations made during the meeting. The oral presentations, as described in the Agenda (pages 5-6), had the following titles:

** Assessing Vessel-Induced Water Velocity Changes Using Physical Models - Ms. Sandra Martin, WES.

† Assessing Biological Responses with Laboratory and Field Studies - Dr. Barry S. Payne, WES.

†† An Overview of the Long-term Resource Monitoring Plan - Dr. Ken Lubinski, USFWS.

‡ Use of Delphi Procedures for Evaluating Commercial Traffic Effects - Mr. Jerry Rasmussen, USFWS.

‡‡ Larval Fish Distribution Studies - Mr. Don Hershfeld, CEORH.

§ Monitoring Biotic Parameters to Assess Environmental Effects - Dr. Andrew C. Miller, WES.

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17-18 April 1990

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Strategies to Measure and Predict Physical and Biological Effects of Commercial Navigation Traffic

17-18 April 1990, St. Louis, MO

AGENDA

17 April 1990

0700-0800	Registration
0800-0815	Welcome - Mr. Phil Pierce, OCE
0815-0845	Purpose and Objectives of the Workshop - Dr. Andrew C. Miller, WES
	Session I: Physical Effects Studies
0845-0905	Assessing Vessel-Induced Water Velocity Changes Using Physical Models - Ms. Sandra Martin, WES
0905-0925	Measuring Physical Effects of Vessel Passage Using Field Techniques - Dr. Nani Bhowmik, IL Water Survey
0925-0945	Use of Hydrodynamic Models for Evaluating Physical Effects of Commercial Traffic - Dr. Larry Daggett, WES
0945-1000	Discussion
1000-1015	Break
1015-1045	Application of Existing Information and Techniques to Predict Physical Effects of Vessel Passage - Dr. George Kincaid, CEORH
1015-1200	Panel Discussion I: Strategies for Predicting Physical Effects of Vessel Passage (Bhowmik, Daggett, Kincaid, Martin)
1200-1300	Lunch (on your own)
	Session II: Biological Response Studies
1300-1320	Assessing Biological Responses With Laboratory and Field Studies - Dr. Barry S. Payne, WES
1320-1340	Monitoring Biotic Parameters to Assess Environmental Effects - Dr. Andrew C. Miller, WES
1340-1410	Models for Predicting Impacts of Vessel Passage on Young of the Year Fish and Fish Populations - Mr. Dan Wilcox, CENCS
1410-1430	Discussion
1430-1500	Application of Existing Information and Methods to Predict Biological Effects of Vessel Passage - Mr. Gene Buglewicz, LMV
1500-1530	Break
1530-1545	Panel Discussion II: Strategies for Predicting Biological Effects of Vessel Passage (Buglewicz, Payne, Tippit, Wilcox)
1700	Adjourn
1930-2100	Break-out Session Topics: Strategies for Dealing with Recommendations Made by the 44th Environmental Advisory Board Strategies for Evaluating Traffic Effects - Are There Reasonable Choices?

Strategies to Measure and Predict Physical and Biological Effects
of Commercial Navigation Traffic

18 April 1990

0800-0815	Purpose of Day 2 - Dr. Andrew C. Miller, WES
0815-0830	Summary of Break-out Sessions Mr. Thomas C. Fisher, TVA Dr. Robert Delaney, USFWS Mr. Bernard Schonhoff, Iowa DNT Mr. Richard Tippit, CEORN
	Session III: Large-Scale Studies of Traffic Effects
0845-0905	An Overview of the Long-term Resource Monitoring Plan - Dr. Ken Lubinski, USFWS
0905-0925	An Overview of the Plan of Study - Mr. David Leake, LMS
0925-0945	An Overview of NAVPAT - Mr. Terry Siemsen, ORL
0945-1000	Break
1000-1020	An Overview of Huntington District Studies - Mr. John Furry, CEORH
1020-1040	Larval Fish Distribution Studies, Kanawha River - Mr. Don Hershfeld, CEORH
1040-1100	Use of Delphi Procedures for Evaluating Commercial Traffic Effects - Mr. Jerry Rasmussen, USFWS
1040-1100	Discussion
1100-1145	Panel Session III: Rationale for Choosing Specific Approaches for Studying/Predicting Commercial Traffic (Furry, Hershfeld, Leake, Lubinski, Rasmussen, Siemsen)
1145-1200	Concluding Comments - Mr. Phil Pierce, OCE
1200-1330	General Discussion on Dealing with Traffic Effects - All
1330-1430	Lunch (on your own)
1430-1600	Establishing a Task Force to Deal with Commercial Navigation Traffic Issues - All

CONVERSION FACTORS, NON-SI TO SI (METRIC) UNITS OF MEASUREMENT

Non-SI units of measurement used in this report can be converted to SI (metric) units as follows:

Multiply	By	To Obtain
cubic feet	0.02831685	cubic metres
feet	0.3048	metres
horsepower (550 foot-pounds (force) per second)	745.6999	watts
miles (US statute)	1.609347	kilometres

AN INVESTIGATION OF METHODS TO MEASURE AND PREDICT BIOLOGICAL AND PHYSICAL EFFECTS OF COMMERCIAL NAVIGATION TRAFFIC: WORKSHOP II

Purpose of the Workshop

Dr. Andrew C. Miller*

Diverse opinions exist within the US Army Corps of Engineers on the environmental effects of commercial navigation traffic. Some Corps personnel appear to believe that traffic has many negative effects that cannot be compensated for, whereas others believe the effects to be minimal. This is unusual when one considers the tremendous amount of study that has been done on the environmental effects of commercial traffic. Worse than lack of agreement on navigation effects, few Corps personnel could agree on the best methods of studying or measuring the biological and physical effects of traffic.

In an effort to remedy some of these problems, a workshop was held to discuss the most appropriate techniques for measuring and predicting the physical and biological effects of commercial navigation traffic. Agreement on these issues must be reached if Corps personnel and others are to evaluate the effects of existing levels of traffic, and to predict the effects of future, increased traffic levels. This workshop was attended by biologists and planners within the Corps, the US Fish and Wildlife Service, and State agencies that have the responsibility to deal with environmental problems on major inland waterways. This report contains papers submitted by some of the speakers who made presentations at the workshop. In selected cases, the title of the submitted paper differed from the title of the oral presentation. Both titles are given in the Table of Contents.

Studies are being conducted at the US Army Engineer Waterways Experiment Station to determine the best procedures to measure biological effects of commercial navigation traffic. These studies are providing quantitative data on the effects of commercial traffic on important biotic resources. These data will assist personnel in the Corps and other agencies who deal with effects of commercial navigation traffic. Considerable time and funds will be

* US Army Engineer Waterways Experiment Station, Vicksburg, MS.

saved if resource and construction agencies cease conducting poorly designed studies that deal superficially with cause and effect. Well-designed studies that yield quantitative data are needed. Planners and biologists will then be able to concentrate on issues that need attention. This will improve the credibility of studies conducted by State and Federal agencies and, most important, will increase the likelihood that significant resources along waterways will be protected.

Using Physical Models to Study Navigation-Induced Forces

Sandra Martin and Steve Maynord*

Introduction

On the inland waterways of the United States, particularly on the upper Mississippi and Ohio River systems, determination of the physical forces that result from navigation are complicated by the diverse flow and channel conditions and by the variability of vessels found on the rivers. Physical models have been and continue to be an effective means of bridging the gap between the difficult and sometimes impossible task of measuring these forces in the natural environment and the increasing need to predict how these forces will ultimately affect the environment. This discussion will be devoted to the advantages and limitations of using large physical models; that is, those reduced at most to a 1:25 scale, to evaluate the physical forces produced by commercial tows in confined channels and navigable rivers.

Advantages of Physical Models

The most important advantage of a physical model is that it can provide insight and understanding of flow patterns caused by vessel motion. From the "bank" of the model, the observer can get a panoramic view of the vessel-induced flow phenomena, such as bow waves and return currents, and simultaneously the passing vessel's effects on shoreline water levels. Visualization techniques such as dye injection, plastic beads, confetti, and underwater photography can be used in a model to easily demonstrate water currents and sediment motion. Observation of flow patterns in scale models is not inhibited by adverse wind conditions, passing vessels, and turbid water.

Another major advantage is the control that can be obtained in the model. All parameters can be held constant except for the variable of interest. That is, climatic conditions such as wind, passing vessels, geometric variability, flow conditions, etc. can be monitored, at will, to suit the study needs. This is virtually impossible under field conditions.

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* Both authors are Research Hydraulic Engineers, US Army Engineer Waterways Experiment Station, Vicksburg, MS.

Finally, results of navigation-induced conditions can be easily measured, particularly water levels and velocities. With the advent of new instrumentation such as the laser Doppler velocimeter we will be able to improve the measurements obtained in the model.

Limitations of Physical Models

There are two primary limitations to physical modeling - one regarding similarity laws and the other regarding cost. To overcome the first limitation, it is extremely important that physical model results are verified with prototype data. This is due to the fact that scale effects can be experienced with regard to friction, quantification of sediments, and tow-power relationships, even when using relatively large models. To obtain highly accurate results, especially considering the scale of these models, the initial construction, instrumentation, and testing of these models can be expensive. However, once a comprehensive flume has been constructed, modifications and additional tests can be performed with little expense.

Applying Physical Models to Navigation Studies

Physical models can be used to address the following specific concerns regarding navigation effects:

a. Physical forces near/beneath vessel. Prototype measurement of the forces near or below the vessel can be difficult. Since the parameters such as the propeller type (open wheel or kort nozzle), the channel geometry, vessel speed, tow type, etc., can be controlled in the physical model, the model can evaluate the effects of these parameters on the velocities and strength of the wake flow, the width of the propeller jet attack, and other phenomena occurring near or beneath the vessel.

b. Return velocity distribution. The physical model can be used to evaluate the effect of various tow positions, operating conditions, barge configurations, and channel geometries on return currents.

c. Backwater and side channel analysis. Physical models can be used to evaluate navigation effects on backwaters and side channels. This area is one in which a high potential exists to improve our understanding of physical processes. Either a site-specific or a generic backwater area could be modeled with and without tow traffic to formulate analytical descriptions of the sediment-flow interactions in these areas.

d. Evaluation of the ambient velocity effects. All existing numerical models of physical forces add and/or substract the ambient river velocities from the tow-induced velocities. It is extremely important, and completely conceivable, to validate this assumption in a physical model where tows can be run upbound, downbound, and in variable river currents, including slack waters.

e. Physical forces at high flows/stages. An important advantage of physical models is the ability to reproduce catastrophic or unusual flow conditions that are either impossible to measure in the prototype or for which historical data are not available. Consequently, much can be gained by reproducing extreme riverine conditions and evaluating the navigation-induced forces that occur under these conditions.

Accomplishments Using Physical Models

Many studies have been done abroad that investigated the forces around vessels using physical models. They have addressed problems or reproduced conditions specific to the objectives of those studies. For example, they have evaluated large ship traffic in confined channels, translatory waves in locks, limiting vessel speed, squat, etc. In general, the European work has been primarily applicable to small channels, whereas the studies that have been conducted at the US Army Engineer Waterways Experiment Station (WES) have attempted to address problems more related to the towboat traffic and the type of conditions found in the upper Mississippi and Ohio River systems.

The flow conditions produced near and beneath a towboat are complex and three-dimensional. These flow conditions are affected by physical conditions such as the shape and size of the vessel, its horsepower and propeller type, the channel shape and size, the ambient current, the speed of the vessel, etc. Physical model studies conducted at WES have demonstrated how the bow wave, drawdown, displacement flows, propeller jets, etc., relate to the physical parameters.

In work conducted by WES for the Louisville District, flow visualization and velocities measured beneath the vessel in a 1:20-scale model have shown that prop jets are not the only mechanism that caused increases in turbulence intensity and velocities*. Other mechanisms that have a significant effect on

* Maynord, S. 1990. "Velocities Induced by Commercial Navigation," Technical Report HL-90-15, US Army Engineer Waterways Experiment Station, Vicksburg, MS.

the flow beneath the vessel include bow wave, displacement flows, and wake flows. Physical model studies have produced analytical relationships based on the empirical data described, at least one-dimensionally, by some of these mechanisms.

Many European studies have been conducted regarding return currents in "confined" channels. These studies have produced several analytical equations for the calculation of these currents and have shown, intuitively, that the strength of these currents diminishes with the width of the channel. Return velocity distributions have been studied at WES at three different model scales, 1:35, 1:70, and 1:120. Observations in the field have indicated, however, that return currents may be of significant magnitude in much wider channels than those that have been studied in the laboratory.

Several studies have been conducted at WES that address navigation-induced forces by taking measurements of the water level changes and velocities near and beneath the vessel. These studies have primarily been devoted to towboat waves and drawdown as they are related to slope stability and riprap protection. Bank protection was evaluated for the Tennessee-Tombigbee project,* the new Gallipolis lock approach, and the Point Marion Lock approach at 1:20, 1:25, and 1:15 scales, respectively. The Technical Report entitled "Riprap Protection on Navigable Waterways"** contains both general and site-specific results of studies addressing the effects of navigation on channel bottom stability. Although these studies provide useful and much-needed information regarding the effects of towboat traffic, there is still much left to accomplish, especially regarding environmental concerns on the upper Mississippi River.

Conclusions

In order to measure and predict the impacts of commercial traffic on both the physical and biological environment, it is vital not only to understand and quantify the physical forces created by the vessel, but also to

* Maynord, S., and Oswalt, N. 1986. "Riprap Stability and Navigation Tests for the Divide-Cut Section Tennessee-Tombigbee Waterway," Technical Report HL-86-3, US Army Engineer Waterways Experiment Station, Vicksburg, MS.

** Maynord, S. 1984. "Riprap Protection on Navigable Waterways," Technical Report HL-84-3, US Army Engineer Waterways Experiment Station, Vicksburg, MS.

determine how these forces interact with river currents, sedimentation, and biological resources. Physical models can be extremely useful tools when evaluating the phenomena associated with tow-induced forces and their effects on the riverine environment in which they operate. Data obtained from the model can provide direct answers to specific questions regarding currents and sediment movement, produce empirical data for the development of numerical algorithms for use in mathematical models, and identify potential sites for prototype testing.

Demographic Analysis of Populations in Evaluations of Environmental Effects of Navigation Traffic

Barry S. Payne*

Background

Measurements of population condition are applicable to analysis of ecological consequences of commercial navigation traffic. These direct biological assessments lead to inferential evaluation of aquatic habitats (e.g., Payne, Bingham, and Miller (1989), Payne et al. (1989)) and both contrast with and complement habitat-based evaluations such as the US Fish and Wildlife Habitat Evaluation Procedures and the Instream Flow Incremental Methodology. Such habitat-based methods directly assess habitat and lead to inferential evaluation of specific biological populations. Both population- and habitat-based assessment methods can be used for pragmatic and quantitative environmental analysis.

The condition of any population is determined by the net result of recruitment, growth, and mortality of individuals. Recruitment, growth, and mortality can be assessed by measuring the relative abundance of individuals of different sizes (and ages). Such assessments of size demography have been the basis of a highly quantitative and fruitful line of pure and applied studies of aquatic animal life histories (e.g., Russell Hunter (1953), Fremling (1960)) and, more recently, production (e.g., Ivlev (1966), Waters (1969), Hunter (1975), McMahon (1975)). The practicality and established scientific credibility of such direct biological assessments make them useful in applied studies such as efforts to determine the effects of commercial navigation traffic in large inland waterways.

An Example of Mussel Habitat Condition in the Lower Ohio River as Assessed from Population Size Demography of the Ebony Shell Mussel

The ebony shell, *Fusconaia ebena*, is the dominant mussel of mainstream shoals in the lower Ohio River (Miller, Payne, and Siemsen 1986). Mainstream

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river shoals are the principal habitat of *F. ebena* and most species of freshwater unionid mussels. Unionids are a natural resource of commercial, ecological, and aesthetic value, and 25 species are on the Federal List of Endangered Species. Protection of riverine mussels and their habitat is an important concern of the Corps and natural resource management agencies.

Demographically complete censuses have rarely been made of unionid populations in mainstream river shoals (Miller and Payne 1988) despite great attention that is focused on preservation of these animals. Unique among freshwater bivalves, large, thick-shelled unionids that have adapted to life in river shoals combine a long reproductive life with high reproductive output each year (Coker et al. 1921; Chamberlain 1931; Burky 1983). Annual variation in recruitment success is often a critical aspect of the dynamics of populations with such life history features. The condition of a mussel bed cannot be adequately assessed without quantitative information on recruitment (Miller and Payne 1988).

Methods and Description of Study Area

The mussel bed studied is located in the lower Ohio River downstream of Lock and Dam 53, the downstreammost impoundment of the Ohio River (Miller, Payne, and Siemsen 1986). This mussel bed is approximately 5 km in length and occurs on the channel border adjacent to the Ohio River navigation channel. *Fusconaia ebena* is the dominant mussel in this bed, comprising approximately two-thirds of the total community. The size demography of this dominant population was assessed during each of the 3 years as part of a long-term monitoring study of this mussel bed (Payne and Miller 1989). Replicate quantitative samples of substrate were collected in the fall of 1983, 1985, and 1987 by divers equipped with scuba and sieved to obtain all mussels regardless of size. The shell length (SL) of each mussel was measured, and SL frequency histograms were plotted.

Results and Discussion

Seventy-one percent of all *F. ebena* collected in 1983 belonged to a single cohort of 1981 recruits with an average SL of 16 mm (range 13 to 20 mm) (Figure 1). By the fall of 1985 this cohort had increased in average SL to 30 mm (range 23 to 38 mm), and still comprised 71 percent of the total

population of *F. ebena*. Continued linear growth of this cohort led to an average SL of 47 mm in late September 1987 (range 36 to 56 mm), and relative abundance of the cohort remained high (74 percent). The sustained high relative abundance of this cohort was reflected in its low mortality from 1983 to 1987, plus the lack of any extensive new recruitment of younger cohorts during that period (minor recent recruitment was indicated in the results of the 1987 sample) (Figure 1).

Much concern exists that increased frequencies of navigation traffic in inland waterways will deleteriously affect mussels via increased turbulence and resuspension of bottom sediments. This population of *F. ebena* in the lower Ohio River has existed for decades (Williams 1969) in a shoal bordering the commercial navigation lane. Data summarized in Figure 1 clearly demonstrate that annual recruitment success is the principal determinant of the abundance of mussels in this shoal. Studies are continuing to determine what environmental factors were responsible for the exceptionally strong recruitment noted in 1981. Nonetheless, it is highly improbable that a unique condition of navigation traffic in the lower Ohio River in 1981 accounted for recruitment in that year at orders of magnitude greater than in other years from 1981-1987. Survival of the 1981 recruits has been high despite the proximity of this shoal to a major commercial navigation lane.

The continued existence of most unionids in large inland rivers depends on protection of remaining beds and stable shoals from destruction by impoundment, dredging, or sustained degradation of water quality as well as prevention of overharvesting of commercially exploited mussel beds. Assessments of the health of remaining mussel beds must be based on long-term quantitative studies of recruitment, growth, and survival of cohorts of dominant populations. Periodic assessment of size demography of *F. ebena* in the lower Ohio River (Figure 1) demonstrates how such measurements can allow quantification of recruitment, growth, and mortality rates.

Guidance on Assessment of Population Size Demography

Assessment of population size demography is straightforward, typically relying on construction and interpretation of size frequency histograms. Size frequency histograms are constructed by: (a) sampling a large number of individuals (required sample sizes will be discussed in the next section) essentially without bias due to variation in the size of individuals, (b) measuring

the size of each individual (typically a length measurement is taken), (c) sorting individuals into size class intervals, and (d) determining the frequency of occurrence of individuals per size class. The histogram is then plotted and inspected to determine how many distinct size groups (cohorts) are present.

A critical choice is the number of class intervals to be used. The number of class intervals that should be used is proportional to the number of individuals in the sample and the precision and accuracy of individual size measurements. However, no rule exists to determine the appropriate number of class intervals. Final choice can depend on preliminary analysis of several plots using different-sized class intervals. In general, 25 to 50 class intervals are appropriate for most applications based on moderately large samples (50 to 200 individuals).

Both sample size and the number of size classes used to construct size frequency histograms directly affect interpretation of population size structure (Figure 2). Figure 2a presents a shell length (SL) frequency histogram constructed for an unusually large sample (n = 2,272) of the Asiatic clam *Corbicula fluminea* from the lower Ohio River. For such enormous samples, the limits for size class intervals are determined by measurement accuracy and precision rather than sample size. Calipers were used to measure SL to the nearest 0.1 mm (measurement precision). Despite such precise measurement of SL, repeated measurements of single clams indicated that accuracy of SL measurement was approximately 0.5 mm. Based on this accuracy, and the need to rapidly process a high number of large samples, SL was recorded to the nearest 1.0 mm (caliper measurements could be quickly read to the nearest 1.0 mm or, at a far slower pace, to the nearest 0.1 mm). Clams ranged in SL from 6 to 33 mm (sampling method did not collect clams < 4 mm). Thus, a total of 28 class intervals were used to determine the relative abundance of individuals by size class (Figure 2a). Five cohorts were evident, although two of these (cohorts III and IV) were especially abundant and one (cohort I) was rare.

The SL frequency histogram plotted using the same class interval size (1.0 mm) but a moderately large sample (n = 214) (Figure 2b) revealed the same size demography with one exception. A few individuals (n = 3) from cohort I were included in the sample of 214 clams, but this rare cohort could not be distinguished in the moderately large sample. Forty-eight individuals of cohort I were included in the exceptionally large sample on which Figure 2a

was based. Adjacent cohorts often cannot be distinguished if fewer than 20 individuals per cohort are included in the population sample. In addition, reduced growth rate of larger and older animals can create difficulty. For example, the largest and oldest cohorts (I, II) in Figure 2a are more closely spaced than are the smallest and youngest cohorts (III, IV, and V). The oldest cohorts in exceptionally long-lived populations (such as some riverine mussels that live 10 to 20 years) typically cannot be distinguished in a size frequency histogram even when each cohort is adequately represented (i.e., > 20 individuals) in the population sample).

A second SL frequency histogram was constructed for the moderately large sample of *Corbicula fluminea* in the lower Ohio River to demonstrate information loss resulting from use of too few size class intervals (Figure 2c). The same SL data sorted into 1.0-mm class intervals for Figure 2b was sorted into 2.0-mm intervals (reducing the number of size classes in half) for Figure 2c. Cohorts II and V were not distinguishable in this coarse-grained analysis, although the two dominant cohorts (III and IV) were still distinguishable.

Use of fewer than 20 class intervals is appropriate for small samples (< 30 individuals). Such small samples and coarse-grained analysis are adequate for basic aspects of population size demography (e.g., general information on total size range of individuals and identification of especially abundant size classes). The finest details of size demography of a population may be revealed only by exceptionally large samples and fine-grained analysis. Huge numbers of individuals of dominant macroinvertebrate populations are routinely obtained in samples of exceptionally dense populations, and such samples can be used for extremely detailed description of size demography (e.g., Figure 2a). However, moderately large samples will reveal most important aspects of discernible population size structure (Figure 2b).

Discussion

Measurement of population size demography is a direct method of biological assessment that can be used for inferential evaluation of aquatic habitat conditions. Especially when particular animals are of high interest and abundant (such as mussels in the lower Ohio River), direct assessments are a practical and highly quantitative method of environmental analysis. Furthermore, basic quantitative information on population conditions and life history that

result from such direct assessment of size demography provide important baseline information relevant to future environmental evaluations.

The studies exemplified herein of *Fusconaia ebena* involved repetitive assessments over a number of years, but important information can also be gained from single date assessments. The first assessment of the size demography *F. ebena* in the lower Ohio River (1983 in Figure 1) revealed the most important characteristic of this population -- namely, a single cohort of recent recruits dominates these long-lived mussels. Subsequent monitoring was conducted for growth and mortality evaluations of this dominant year class.

Quantitative assessments of size demography of dominant macroinvertebrate populations can be accomplished with no more effort and expense than is typically spent on descriptive characterization of macroinvertebrate communities. Such general community characterizations are a common component of aquatic environmental evaluations. It is noteworthy that accurate information on species relative abundance, richness, diversity, and evenness can be provided as part of studies of the size demography of dominant populations (e.g., Miller and Payne 1988; Payne, Bingham, and Miller 1989).

Assessments at the population level of biological organization are especially valuable in applied studies. Biological effects of man's activities in aquatic habitats can also be assessed at the organismal or community (groups of co-occurring populations) levels of organization. Studies at the individual level often lack ecological relevance without confirmation of effects at the population or community level. For example, mortality of individual organisms often has no discernible effect due to compensatory responses in population dynamics. Community level studies, although of clear ecological relevance, are greatly hindered by the prevalence of locally uncommon species in nearly all natural communities. This makes completely accurate sampling of communities (especially with replication) practically impossible Accurate and replicated sampling of dominant populations is much more feasible. Not surprisingly, the most convincing conclusions of many community studies are those based on analysis of responses of dominant species. As demonstrated herein, size (and age) structure are among the most important and practical measurements that can be made of dominant populations.

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Models for Predicting Impacts of Vessel Passage on Young of Year Fish and Fish Populations

Daniel B. Wilcox*

Introduction

Commercial vessel traffic may have a significant effect on fish eggs, larvae, and juveniles that occur in navigation channels. Entrainment of young of year (YOY) fish in commercial vessel propeller flow appears to expose organisms to lethal hydraulic forces. The impact of entrainment losses of YOY fish can be realized at the population level, and in forage production foregone. The impact mechanism is similar to the entrainment and loss of fish at steam-electric power plants. Some of the approaches to quantifying the impact of powerplant entrainment on fish populations have application to assessing the impact of commercial vessel traffic. Some of the basic modeling approaches used in powerplant entrainment impact assessment are described. Application of these modeling techniques to assessing commercial vessel impacts will require interagency agreement on approach, and considerable effort to refine model parameters to limit uncertainty in results.

Impact Mechanism

Fish eggs, larvae, and juveniles occur in large numbers in the navigation channels of waterways. Their species composition, life stage, density, temporal occurrence, and position in the channel cross section are quite variable. This variability is influenced by the phenology of fish reproduction, the reproductive strategies of different fish species, the hydrology of the river, and the behavior of young fish.

Towboats entrain large volumes of water in propeller flow. This volume has been initially estimated using a scale physical model, to be about twice the propeller area times the distance travelled.** Shear, acceleration, pressure change, and direct impingement can kill young fish (Marcy, Beck, and

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** Personal communication, 1990, Stephen Maynord, Fishery Biologist, US Army Engineer Waterways Station, Vicksburg, MS.

Ulanowicz 1978). Velocities in excess of 3 m/sec in the propeller flow of commercial vessels generate shear, acceleration, and pressure changes that appear to be of sufficient magnitude to kill fish eggs and larvae (Academy of Natural Sciences of Philadelphia 1980; Killgore, Miller, and Conley 1987).

Entrainment losses of YOY fish can result in reduced recruitment and decline of populations. This impact is realized at the population level if entrainment losses exceed the compensatory reserve of the population (the ability of a population to offset increases in mortality). Reductions in populations of sport and commercial fish species translate to fishing opportunity denied, and associated economic loss (Goodyear 1988).

Entrainment losses of YOY fish also reduce available forage. Entrainment losses of forage fish can result in reduced numbers and biomass of forage fish and may affect growth of survivors. Reduced abundance of forage fish can affect populations of piscivorous fishes and birds.

Approach to Impact Assessment

The impact of vessel entrainment is analogous to entrainment of fish at powerplants. Modeling approaches used to assess powerplant entrainment impacts (Schubel and Marcy 1978) have application to assessing the impact of vessel entrainment impacts.

Estimating Entrainment Losses

First, entrainment losses can be estimated using an algebraic equation that incorporates pumping rate, entrainment mortality, river volume, and an estimate of natural mortality (Englert and Boreman 1988). In more complex systems, empirical transport models have been developed to incorporate hydrodynamic detail, age of fish, and temporal and spatial distribution of fish (Boreman and Goodyear 1988). The objective is to model the percent reduction (PR) of yearling fish numbers due to entrainment losses:

$$PR = 100\,(Y_o - Y_p)/Y_o \qquad (1)$$

Y_o is the number of age-0 fish surviving to become yearlings without the impact, and Y_p is the number of age-0 fish surviving to yearlings with

impact. The PR has also been called conditional entrainment mortality rate (Boreman, Goodyear, and Christensen 1981). The conditional entrainment mortality rate is defined as the fractional reduction in year-class strength due to entrainment if other sources of mortality are density-independent.

Entrainment mortality can be conservatively assumed to be 100 percent. Ignoring potential entrainment survival, however, can lead to an overestimate of entrainment impacts on fish populations. Refinements of towboat entrainment mortality rate could be accomplished by the same methods used to estimate powerplant entrainment mortality: field prototype experiment, laboratory simulation with a scale physical model, or numerical hydraulic modeling to estimate magnitude of hydraulic forces coupled with laboratory assays to determine survival. Experimental design must be carefully controlled in tests using live fish to determine entrainment mortality to attain statistically supported results (Vaughan and Kumar 1981).

Estimating population-level impact

The impact of entrainment losses on fish populations can be estimated with considerable confidence if sufficient information exists about the affected population. Unfortunately, most stocks of fish in inland waterways have not been assessed and there are few fish population statistics to use for impact assessment.

Lacking population statistics, an indirect method can be used in which the numbers of eggs, larvae, and juveniles entrained are converted to an estimate of the number of adult fish that would have been produced had entrainment mortality not occurred (Horst 1975). A number of refinements of this approach have been developed to assess powerplant impacts. This general approach has come to be known as the "equivalent adults" or "eggs per recruit" method. If the entrained stage is an egg, the estimate of the number of adults lost is calculated as:

$$N_a = S_g N_e = (2/F) N_e \qquad (2)$$

where

N_a = number of adults

S_g = survival from egg to adult

N_e = number of eggs entrained

2 - number of adults needed to be produced by a breeding pair to maintain a stable population

F - total lifetime fecundity of a female based on generation time (g) of the population and the average fecundity

Estimates of survival from entrained age to adult and fecundity estimates are gleaned from the fisheries literature. Refinements to this modeling approach have included sensitivity analyses of the input variables, improved statistical treatment of input data, and measures to account for biological compensation.

Estimating production foregone

Entrainment loss impacts on the forage base can be estimated by estimating production (body mass produced by a population over a period of time) foregone (Rago 1984). This direct approach is based on exponential mortality and growth. An indirect method, based on exponential mortality and the von Bertalanffy growth equation, can be used to provide a more complete assessment of production foregone (Jensen, Reider, and Kovalak 1988).

Information Requirements and Predictive Value

An assessment of entrainment impacts requires modeling of entrainment losses and population-level impact. There is a high degree of uncertainty in entrainment impact modeling because there is a high degree of uncertainty in estimation of many model parameters. There have been only initial efforts to quantify vessel-induced entrainment impacts at the population level, and considerable information is required.

Predictive value increases with increased certainty of results. A tiered impact assessment approach may be appropriate, where conservative estimates are used throughout, to provide a relatively certain order-of-magnitude prediction of impact. If initial conservative predictions indicate minimal impact for certain river reaches, further investigation may not be warranted. Sensitivity analyses of models to be applied in impact assessment should be conducted to determine input variables where effort to quantitatively refine the variable estimates would pay off in increases in certainty of results.

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Application of Existing Information and Methods to Predict Biological Effects of Vessel Passage

Eugene Buglewicz*

Background

The Corps of Engineers, by the nature of its work, precipitates decisions. The Corps and other water resource construction agencies follow a rigorous set of guidance to assess biological effects of vessel passage. The purpose of this paper is to put into perspective those sometimes conflicting and contradictory aspects of providing reasonable evaluations of navigation traffic impacts and the "real world approach," the implications for future planning efforts.

The intent is not to reiterate the Planning Principles and Guidelines,** but rather to explain some of the key definitions and procedures that govern to a large extent how the Corps evaluates projects, and relate them to our current planning process. We in the Corps work under specific rules and regulations. We must have the proper authorities to carry out our activities, while being consistent with the requirements of law and the policies of our organization.

"Economic and Environmental Principles and Guidelines for Water and Related Land Resources Implementation Studies," or "Principles and Guidelines," as they are more commonly called, were developed to guide the formulation and evaluation studies of the major Federal water resources development agencies. The other Federal agencies include the Bureau of Reclamation, Tennessee Valley Authority, and the Soil Conservation Service. The Principles and Guidelines have their foundation in law, Section 103 of the Water Resources Planning Act, Public Law 89-90, and Executive Order 11747. The Principles portion of the document was approved by the President in February 1983, and the Chairman of the Water Resources Council approved the Standards and Procedures in March of 1983. If you take careful note of the booklet, it is divided into two major sections. The Principles are a relatively short

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** Water Resources Council. 1983. "Economic and Environmental Principles and Guidelines for Water and Related Land Resources Implementation Studies," Washington, DC.

statement of economic and environmental principles in which the Federal objective is defined. The Standards begin on page 1, and constitute the detailed procedures we must follow in our plan formulation process.

The second publication is called the "Planning Guidance Notebook."* The notebook is also known in the Corps of Engineers as ER 1105-2-100, and has been in draft form since May of 1989. This publication incorporates the requirements of the "Principles and Guidelines" as well as the changes that have occurred in the planning process as a result of the passage of the Water Resources Development Act of 1986.

The other document that impacts our planning to a great extent is the National Environmental Policy Act, or NEPA. The "Principles and Guidelines" incorporate NEPA requirements, which are incorporated into our ER 1105-2-100. Thus, by following our guidance, any project should be in compliance with the Principles and Guidelines, NEPA, and our policy guidance.

As you know, the Corps of Engineers uses a two-phase planning process, the first phase called reconnaissance, and the second phase called the feasibility phase. Each phase requires different levels of information. Both phases depend on one another, and in fact, the first phase, reconnaissance, is perhaps the most important, and is the one I will spend more time on today. It is important because decisions made during reconnaissance are going to determine success or lack of success during the feasibility phase. Second, the allowed time frames for accomplishing reconnaissance and our budgeting process demand that you begin to make decisions about the feasibility phase even before the reconnaissance phase has begun. How that problem is to be handled and how that is going to relate to the need for navigation traffic impact information is of vital concern to us here today.

The purpose of a reconnaissance phase study is to determine whether or not there is a Federal project for which we should proceed to the more detailed feasibility phase. In reconnaissance, there must be a preliminary determination of the presence and general location of significant resources within the study area, and the likely effects of project alternatives on those significant environmental resources. The reconnaissance study will require a thorough discussion of potential mitigation measures and possibly a determination of the type of NEPA document that will be required. The reconnaissance

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* US Army Corps of Engineers. "Planning Guidance Notebook," Engineer Regulation 1105-2-100, Draft Regulation, Washington, DC.

report must contain a scope of work to conduct fish and wildlife surveys, studies or analyses proposed for the feasibility phase. Since the reconnaissance phase is constrained to a 12-month time period, there will be precious little time to do much, if any, field analysis. Therefore, letters to appropriate resource agencies and interested publics, site visits, and possibly some minor surveys will be possible in the study area. During reconnaissance, the project biologist is basically constrained to using available information. In the case of large navigation projects, there is a possibility that the reconnaissance phase may be extended to a longer period of time (with permission from Headquarters), but the most we should plan for is 6 additional months. During reconnaissance, the Corps planner must look ahead to feasibility, because in feasibility the planning process demands a NEPA document and justified mitigation requirements for the recommended plan and all alternatives that entered into the final array. During reconnaissance, Corps biologists are going to have to rely on their ability to foresee resource problems. When the topic is navigation, and impacts result from vessel traffic, scopes of work will have to be carefully designed to answer specific resource questions that surface during reconnaissance.

Our guidance provides definitions we should be conversant with. They are important because they narrow our focus to deal with important resource questions and provide an indication how and where we should be anticipating mitigation requirements. These important definitions are:

Significant - A situation that is likely to have a material bearing on the decision-making process.

Significant resource - A national form, process, or system that is identified based on institutional, public, and technical recognition.

Significant effect - A situation in which estimates of future with- and without-plan conditions of the resource are different.

Study area - For NEPA purposes, and by definition, the area over which there are potential impacts.

Mitigation - A commonly misunderstood word but one that includes:

- Avoiding an impact.
- Minimizing an impact.
- Rectifying an impact by repairing, rehabilitation, or restoring, reducing, or eliminating, and impact by preservation or maintenance through the life of the project.

- Compensation through replacement (in-kind) or substitution (out-of-kind) but at least equal in value and significance to lost resources or environments.

- Mitigation measure - An action or feature of a mitigation project.

Our guidance provides us some tests in which we can determine significance.

a. The significance of fish and wildlife resources shall be based upon both their monetary and non-monetary (environmental quality) values. Both monetary and non-monetary values shall be identified and clearly described.

b. Monetary value shall be based upon the contribution the resource makes to the nation's economy.

c. Non-monetary value shall be based on technical, institutional, and public recognition of the ecological attributes of the fish and wildlife resources in the study area.

d. Criteria for determining significance shall include, but not be limited to, the scarcity or uníqueness of the resource from national, regional, state, and local perspectives.

e. Non-monetary values associated with fish and wildlife resources are subjective, and depend on the value society places on them. Differing values and concerns shall be documented, including the rationale used to select values chosen to determine resource significance.

f. Lastly, our guidance provides a methodology to determine those values:

The monetary and non-monetary values associated with fish and wildlife resources arise primarily from the quantity and quality of the habitat within the study area. Therefore, habitat-based evaluation methodologies, supplemented with production, user-day, population census, or other similar information shall be used to describe and evaluate fish and wildlife resources and impacts associated with alternative plans.

It is clear what our guidance requires in the analysis of significant resources. A good planner will focus on quantity and quality of habitat. The first tool any waterway study must have available to it is some type of habitat description. The lower Mississippi River, for instance, is essentially an uncontrolled river with river stage varying 30 ft* and more on an annual basis. Habitats are described such that an area may change habitat type based on river stage. It is a physically based habitat system, a most useful and reliable habitat system using the physical characteristics of the aquatic

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* A table of factors for converting non-SI units of measurement to SI (metric) units is presented on page 7.

system such as water depth, substrate, current velocity, relative volume, and so on.

The second tool is data on biological resources collected by habitat type. There must be reliable information on the biological resources in the habitats in order to determine if alternative plans have any impacts. If resource information is not available, studies must be designed to collect it during feasibility.

Biological information is very difficult to recover in a short period of time. Field studies are labor intensive and usually must be carried out over a period greater than 1 year. Assuming a 3-year period for carrying out the feasibility phase, assuming the "real-world budgetary delays," and the need to produce draft and final reports by the end of 3 years, practically speaking, a planner will have a maximum of 2 years to conduct field work on any particular waterway. The opportunity to have all the population and habitat information at hand to make project alternative evaluations and mitigation recommendations is limited.

Mathematical models can be used to compare relative environmental impacts of alternatives. Math models, or any mathematical representation of biological, physical, or habitat systems, are based on assumptions which are translated into equations or curves that attempt to describe some process or relationship. Mathematical models can translate a collection of hypotheses into representations of the system we are attempting to describe. Some models can be used to describe current conditions, while others may be used to predict future conditions. When choosing a model for alternative plan assessments, however, there are some cautions that must be exercised:

a. The user must understand the problem being researched, and must be able to describe it.

b. The assumptions on which the model is built must be based on knowledge of the system.

c. The user must be able to describe the major components of the system.

d. There should be a describable relationship between major components of the system, and

e. The user must be able to specify the output of the model.

Guidance requires that habitat quality and quantity determine impacts. If the result of our analysis cannot be expressed in some type of habitat descriptor, other methods of dealing with impacts will have to be found. In

the case of navigation traffic impacts, there is no off-the-shelf model that can be used to deal with multiple waterway resource problems.

We can, however, deal with vessel impact analysis. Vessel impact analysis depends on two preconditions:

a. The waterway must be categorized by habitat. Our guidance demands it and justification of mitigation measures require it.

b. Resource components of each habitat and the importance of the habitat to that resource component must be documented.

If this information is not available, each District should set out in a systematic way to collect it, and collect it in advance of the normal planning sequence, before decisions have to be made, and in time periods which are acceptable for collecting biological systems information. Methods that can be used to supplement basic habitat delineation and significant resource components information include:

a. Resource-specific studies. These should be conducted during the feasibility phase to investigate specific impacts. These studies are designed to answer problem-oriented questions. Field and laboratory investigations are appropriate.

b. Resource-specific models. Models are employed to understand interrelationships between and among habitats and resources. Models can test one variable at a time to help us understand our observations. Models can assist in designing field and laboratory studies.

c. Evaluation of new methods and technology. Test and evaluate new technology for responsiveness to study requirements.

d. Use good judgment. Evaluate the results of the information gained through field and laboratory experiment, through model application, and based on the resource base and habitats affected. Does it make sense?

All biological evaluation methods have their strong points and use assumptions based on our understanding of how ecological systems work. Corps biologists must be able to use these tools effectively and efficiently, particularly in the project planning phase when time is minimal and decisions must be made early on which affect the success of our planning effort. Biological assessment in the reconnaissance phase must be based on current data and sound biological principles, recognizing the requirements of law, policy, and organizational guidance.

The first step in assessing navigation vessel movement impacts is to develop a habitat classification of the waterway. The initiation of the reconnaissance phase is too late to begin to plan to develop a habitat

classification; it is too late to begin characterizing the significant resources of the waterway. Corps biologists must be cognizant of the requirements of our planning guidance and anticipate the information needs before the planning process begins. Habitat classification and characterization of the significant resources in those habitats must be available at the initiation of the reconnaissance phase if the biological analysis is to evaluate project alternatives and mitigation requirements in the short time periods available during the planning process.

An Overview of LTRMP Long-term Research Strategies for Navigation Impacts

Kenneth S. Lubinski*

Introduction

The Long-term Resource Monitoring Program (LTRMP) for the upper Mississippi River System (UMRS) was authorized under the Water Resources Development Act of 1986. It provides many of the research functions for a larger program known as the Environmental Management Program (EMP). The LTRMP is funded through the US Army Corps of Engineers and was implemented by the Environmental Management Technical Center, a unit of the US Fish and Wildlife Service. The LTRMP has the following objectives (Rasmussen and Wlosinski 1988):**

a. Analyze and recommend solutions to significant resource problems such as sedimentation, navigation, and water level fluctuatic impacts.

b. Monitor selected habitats and species.

c. Develop data management systems and techniques to assist decision makers in managing the UMRS.

Information needed to describe and explain navigation impacts on the UMRS is generated under two LTRMP program elements: Trend Analysis and Problem Analysis. Information for evaluating methods to restore impacted areas is provided by a separate network of habitat rehabilitation (i.e., backwater dredging, island creation) projects funded under the EMP.

Trend analysis emphasizes the documentation of spatial and temporal patterns of resource components and problems. Six field stations, located to represent floodplain reaches that differ in geomorphology, land use, and anthropogenic influence, provide data related to water and sediment quality, vegetation, and the river's fishery. A major effort under trend analysis includes the use of a Geographic Information System to classify the UMRS into areas that are characterized by different levels of selected physical or

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** Rasmussen, J. L., and Wlosinski, J. H. 1988. "Operating Plan of the Long Term Resource Monitoring Program for the Upper Mississippi River System." US Fish and Wildlife Service, Environmental Management Technical Center, La Crosse, WI.

biological variables. Classification templates are used to spatially extrapolate from the point data collected at field stations to system-wide area coverages. Problem analysis focuses on the measurement and modeling of impacts. Before the selection and funding of specific studies under problem analysis could begin, it was necessary to develop a mechanism for identifying necessary research products. This has been expedited by formalizing impacts hypotheses and outlining a research strategy for each hypothesis.

Strategy Development

The Operating Plan for the LTRMP (Rasmussen and Wlosinski 1988)* listed work tasks that must be accomplished for the successful completion of the program. Based on these tasks, a series of impact hypotheses related to commercial navigation were developed. Examples of impact hypotheses are:

- a. Single commercial traffic events produce short-term changes in turbulence, velocity, shear stress, waves, drawdown, suspended solids, and turbidity in channel and channel border habitats.
- b. Single commercial traffic events increase ichthyoplankton mortality in channel and channel border habitats.
- c. Commercial traffic events cause an increase in the movement of sediment into sidechannels and backwaters.

Hypotheses are designed to define "packages" of research information that can be completed as individual work units. Each hypothesis includes an explicit description of the spatial level (i.e., system-wide, selected river reach, local habitat area) at which the hypothesis is to be tested. When necessary, the time period of interest is described. Short-term physical changes, for instance, may last only 2-5 min, while habitat losses due to navigation-related movement of sediment into side channels or backwaters may occur over a period of decades.

Hypotheses identify specific variables to be investigated. This permits the linkage of physical impacts with consequent biological impacts. Measurements of short-term physical changes associated with traffic events are, as a result, not only used to test the physical impact hypothesis, but also to guide subsequent biological impact experiments.

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* Rasmussen, J. L., and Wlosinski, J. H. 1988. "Operating Plan of the Long Term Resource Monitoring Program for the Upper Mississippi River System," US Fish and Wildlife Service, Environmental Management Technical Center, La Crosse, WI.

The research strategy for each hypothesis includes three lines of inquiry: studies of cause-and-effect relationships; mapping of impact areas; and evaluations of potential solutions. Many of the steps listed under these lines of inquiry (Table 1) are common to most hypotheses being tested. The steps focus on research products needed to comprehensively test a hypothesis.

Steps to study cause-and-effect relationships also assist in distinguishing necessary research products from those that are supplemental. Thus a completed strategy provides a means of prioritizing studies during periods of limited funds.

The most important step in the early phase of this line of inquiry is the construction of a well-defined conceptual impact model. The conceptual impact model (Figure 1) concisely delineates the relationships that require quantification. The model also identifies impact mechanisms. The distinction of impacts caused by separate mechanisms is necessary for assessing impact differences among spatial areas. For instance, the impact model in Figure 1 permits the assumption that jet flow and waves provide different contributions to suspended solids concentrations in different habitat categories.

Mapping of impact areas is necessary to determine when and where defined impact levels occur on the UMRS. Data describing spatial and temporal patterns of selected resource components within the LTRMP Trend Analysis river reaches are generated at field stations. When data from other river reaches are needed, special mapping or spatial extrapolation exercises are implemented.

Mapping steps are facilitated using a Geographic Information System. A variety of spatial products (i.e., elevation, aquatic areas, and land use templates) are being constructed to act as base maps for the identification of problem areas.

An important element for the successful completion of both cause-effect studies and impact mapping is the coordinated definition of impact categories among the Federal and State agencies that will use the data to make management decisions. Coordination meetings are held early in the hypothesis testing schedule for this purpose.

Evaluations of potential impact solutions will require a substantial database and impact models that permit the comparison of reasonable "what-if" scenarios. As a result, comprehensive evaluations are scheduled to be completed late in the program. However, lists of potential management alternatives that could reduce or minimize impacts will be produced as early as

Table 1. Typical Steps Required to Complete the Testing of an Impact Hypothesis

I. Studies of Cause-and-Effect Relationships.

a. List and define input and output variables.
b. Identify and establish probable ranges for environmental variables that influence the relationship.
c. Develop conceptual impact model.
d. Graphically depict relationship(s) to be quantified.
e. Identify minimally acceptable statistical levels of confidence.
f. Identify best available approach (i.e., field measurements, laboratory test, model) to generate required data.
g. Conduct pilot study (if necessary).
h. Collect data.
i. Synthesize data into working model.
j. Confirm results by comparisons to related studies.

II. Mapping of Impact Areas.

a. Define variables to be mapped.
b. Define scope of spatial and temporal coverage.
c. Identify spatial level of resolution.
d. Using results from I, define discreet mapping categories for variables.
e. Select a standardized approach for spatial extrapolation from point data (if necessary).
f. Select base and any accessory maps.
g. Produce and review interim maps.
h. Produce final maps.

III. Evaluation of Potential Solutions.

a. List management alternatives to eliminate or minimize impact.
b. Combine research products from I and II using "What-if" models to compare the effectiveness of management alternatives.

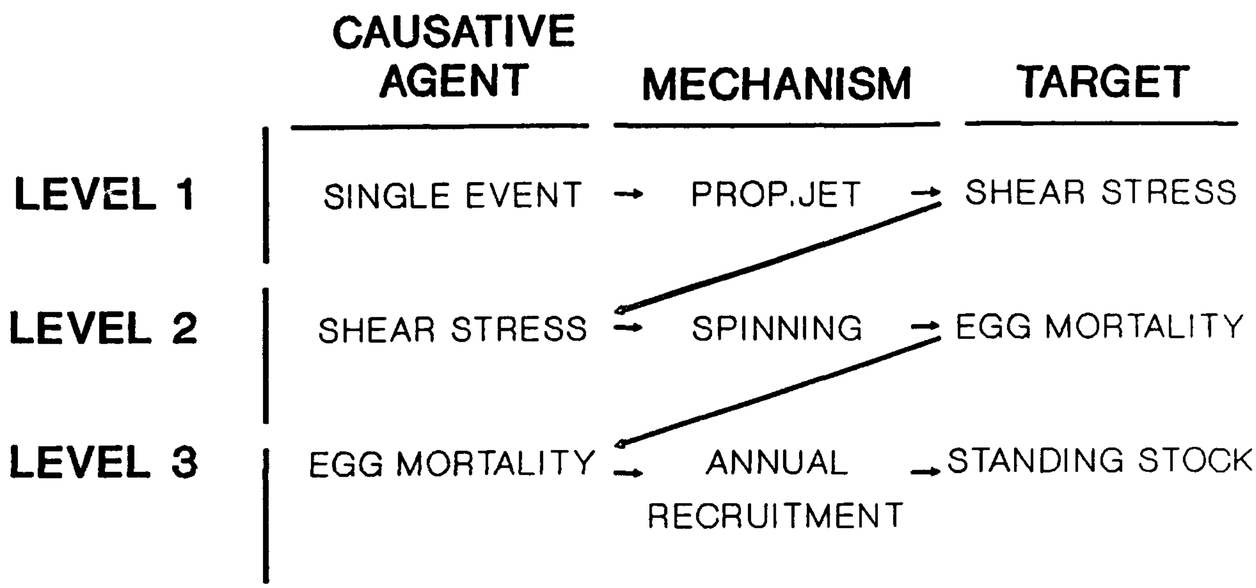

Figure 1. Conceptual impact model for the hypothesis that single traffic events produce short-term changes in target variables (water velocity, shear stress, turbulence, turbidity, etc.)

possible to allow extensive discussion of the alternatives within the scientific, social, and political communities.

Summary

The LTRMP focuses on current and future commercial navigation impacts to natural resources of the UMRS. Research products needed to complete work tasks identified in the program's Operating Plan are being identified and prioritized through a process of formalizing hypotheses and research strategies. Research strategies include studies of cause-and-effect relationships, mapping of impact areas, and evaluations of problem solutions.

Expert Testimony as a Tool for Documenting Resource Impacts

Jerry L. Rasmussen*

Introduction

Use of expert testimony and scientific opinion as resource management or planning tools can be very effective and efficient if properly executed. Expert testimony is not the preferred problem-resolving technique of most resource managers, but time and funding constraints often force them to take that option. Most people would agree that actual data collection and scientific documentation of facts are preferred alternatives.

However, once the decision is made to resolve a problem through expert testimony it is imperative that the process and decision points be well documented, much as they would be in any scientific analysis or evaluation.

Expert testimony was used on the upper Mississippi River on numerous occasions during the 1980's (See References Section). The process used was similar to one commonly referred to as the "Delphi Process." But since techniques used on the upper Mississippi were developed independently of the Delphi Process, the two will not be compared here.

The remainder of this paper will describe five phases of the expert testimony process used on the upper Mississippi.

- Phase I - Problem Evaluation
- Phase II - Organization of Panels
- Phase III - Conduct of Panels
- Phase IV - Panel Operations
- Phase V - Report Preparation

Problem Evaluation

Winston Churchill once said, "A well-defined problem is half solved." That statement holds true for expert testimony as it does for most of life. Care taken to define the limits of a problem pays large dividends in time and resources saved later.

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Once a problem is well-defined, "information needs" can be easily identified through a literature evaluation. It is important here that the so-called gray literature <u>not be</u> overlooked. There is no need to reinvent the wheel, and it is foolish to assume that no one else has ever before confronted the problem at hand, or some facet of it.

Unfortunately, a great volume of scientific data, especially biological data, is buried in files and unpublished documents. This doesn't mean that these data are of no value; most often it simply means that no one has had the time or money to complete the lengthy and expensive formal publication and peer review process. If necessary, the expert testimony process can be used to help validate important gray literature.

Once all existing information has been retrieved, it must be summarized to separate what is known from what is not known. This ensures that data gaps are clearly identified. Data gaps may be extensive and require prioritization. Prioritization further refines and defines the problem, and assists in scoping subsequent efforts.

<u>Organization of Panels</u>

Before proceeding with panel organization, it is important to review budget constraints. A good rule of thumb is that "everything costs more than it costs." Consequently, budget analyses are important and usually dictate the number of data gaps which can actually be addressed.

A review of procedures, guidelines, and avenues available for payment of panel participants is important. There may be mechanisms available to cut costs through cooperative agreements or simple money transfers. In the Fish and Wildlife Service, college and university personnel can often be reached through significantly reduced overhead charges. On the other hand, there may be some experts who are simply not available due to administrative problems or lack of willingness to participate on panels that may end up in court or disqualify them for future work.

Once all constraints are identified, guidelines (i.e., per diem rates, labor rates, etc.) should be developed for payment to participants. This further assists in budget evaluation and assessment of the number of data gaps to be addressed by proposed panels.

The next step is to develop guidelines for panel conduct. Decisions need to be made as to whether the panels will be allowed to run themselves

under a self-elected chairman or whether a chairman or facilitator will be provided by the sponsoring agency. Experts do not always agree, so voting or minority statement procedures must be worked out. Also, the question of permitting or not permitting observers and agency participation must be worked out to the satisfaction of all participating sponsors.

Once these procedures are established and documented, a prioritized list of topics for panel review should be developed. A single data gap may need to be broken down into several topics, and each topic may require a separate expertise. For instance, evaluation of towboat traffic effects on fish populations includes the topics of physical forces in the water column, on the shoreline, and on the biota. Effects on the biota include the topics of fish eggs and larvae, invertebrates, and aquatic vegetation. Inclusion of a separate expertise for each of these topics and subtopics will result in a very large panel.

This leads to the task of identifying "critical" expertise. Panel success depends on having all the necessary expertise available. In the case of the evaluation of towboat traffic effects on fish, the panel would have to include at least the critical expertise of hydraulic engineers and fisheries biologists.

Once the required expertise is identified, procedures must be developed for participant selection. The selection process should be similar to that used by most employers to hire new employees, and it <u>must</u> be well documented. It is critical that selections be unbiased, since panel products, and panel members themselves, could end up in court. Selection criteria should include at least a ranking by education, background, and experience.

Once a list of potential panel members is developed, informational letters inviting participation are sent to all candidates stating the deadline for application. Each candidate then has the opportunity to apply. When the deadline for application passes, applicants are ranked and panel members and alternates selected. It is important to have a list of qualified alternates in case some unforeseen emergency prevents participation of one or more members. However, if an alternate is used, that person permanently replaces (rather than stands in for) the original member. All candidates are then notified of final selections.

Conduct of Panels

Locations and dates for panel meetings must be set as far in advance as possible. Generally, scientists called on as experts are very busy, and it can be difficult to coordinate all their schedules. Depending on the complexity of the problem, more than one panel meeting may be required, and each meeting may last one to several days.

A panel moderator must be selected or appointed to be in charge of meeting proceedings. It is generally advisable to hire the services of a professional facilitator. This enhances panel credibility by eliminating any built-in bias that an agency or sponsor facilitator may bring to the panel. It also frees sponsoring personnel to concentrate on the content rather than the conduct of the meetings.

It may be necessary to record meeting proceedings verbatim, especially if future court action is anticipated. In the later case, it is best to hire a professional court recorder.

Thirty to sixty days before the panel convenes, pre-panel discussion materials need to be prepared and distributed to all members. These materials should include any of the sponsor's assumptions or preliminary conclusions pertinent to the problem, detailed descriptions of data gaps, lists of resources of concern, copies of any scientific articles pertinent to the problem which members may not otherwise have access to, pertinent agency documents, maps, etc.

Panel members should be asked to review pre-panel materials and submit a 2-3 page report on the panel topic, 1-2 weeks before the panel is to convene. Copies of all member reviews and the meeting agenda should be distributed to panel members a few days before the meeting.

Panel Operations

The facilitator should open the meeting with introductions, and then quickly have each member provide a brief oral presentation of his pre-panel report. This will "break the ice" and help establish baseline knowledge and relationships between panel participants early on, getting the meeting off to a quick start. Panels are expensive and time should not be wasted by a lengthy "getting-acquainted" period.

The meeting should then move quickly into discussions of generic impact relationships between the action or project proposed and the resources being evaluated. These discussions help better define resources of concern and set the scope for further panel action. Time should not be wasted discussing resources which the panel feels are unimpacted or of trivial importance. Instead, critical resources and significant impact relationships should be defined or described to the extent possible.

This may be the end point for the first panel meeting if a complex issue such as navigation impacts is the panel topic. Simpler topics could be expected to proceed further or to be concluded in one meeting.

Panel discussions (either at the continuing meeting or at the next meeting) then lead into interactions between the specific project or action in question and the resources of concern. This tailors generic impact relationships and assessment to specific projects or actions being evaluated. If impacts are considered significant, the panel should be led into a discussion of possible avoidance mechanisms or mitigation techniques. The panel should apply impact assessment to both pre- and post-project conditions.

This could also be the end point of the meeting unless the project or action being evaluated is complex and has impacts beyond the immediate project area. In the case of navigation impact evaluation, another meeting may be necessary to apply impact/mitigation information system wide.

At the conclusion of each panel session the facilitator should orally summarize panel conclusions and recommendations. This may stimulate some additional discussion, but it is imperative to good communications and consensus building. Before the panel adjourns, a general understanding and consensus must be reached on what the panel report is expected to present.

Report Preparation

Either the sponsor or the facilitator can prepare the written abstract and summary of findings. Both meeting notes and verbatim transcripts will be helpful in preparing these documents.

The draft abstract and summary of findings are then circulated to panel members for review and comment. Depending on the magnitude of comment and controversy, this may be an iterative process requiring one or more additional drafts.

When all comments have been adequately addressed, the final abstract and summary of findings are prepared and approved by panel members. A panel roster should be transmitted with all documents and a space provided for member signatures. Signatures on the documents enhance credibility of panel findings.

Final documents are then distributed through appropriate channels, and panel products are used as reference documents for further project evaluations.

Summary

As alluded to earlier, the expert panel process described here has been used successfully and to the satisfaction of numerous State and Federal agencies on the upper Mississippi River. Expert opinion formed the basis for decisions made to recommend and fund a major environmental program on that river.

Actual panel topics addressed by those panels and panel membership rosters are displayed on the pages that follow. It should be noted in these displays that expert or impact panels take many forms depending on the complexity of the issues or topics at hand. For example in the case of the upper Mississippi River System (UMRS) Master Plan Impact Panels, large, iterative inter-disciplinary panels were used; and in others, resource professionals were mixed with laymen and met for a single meeting (i.e., the UMRS Master Plan Expert Panel on Commercial Fish and Fishing).

In conclusion, the use of expert testimony on the upper Mississippi has a proven track record. The process described here should work elsewhere and be equally effective for other issues and impact evaluations to build scientific documentation and consensus when time and funds do not allow for lengthy data collection and study.

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ILLINOIS RIVER - December 19, 1985 - Havana, IL
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Kanawha River Larval Fish Distribution and Preliminary Assessment of Entrainment Risk*

Donald C. Hershfeld**

Introduction

One of the environmental concerns surrounding commercial navigation on inland waterways is the potential impact of vessel passage on early life stages of fish, particularly eggs and larvae. Larval swimming ability varies with size/developmental stage and while their evasive capability is considerable (in terms of body lengths traveled per unit time), this mobility takes place over only a small spatial scale relative to the total field of motion induced by passage of a commercial vessel. Depending on their proximity to the sailing line, some larvae are likely unable to avoid encounters with vessel effects. The passage of vessels generates hydraulic conditions which are both complex and variable. Based upon some, but not all, laboratory simulations, repeated exposure to certain of these conditions is sufficient to cause mortality. Attempts to verify entrainment mortality in the field have been made (VPI&SU 1985; Holland 1986) but inherent sampling difficulties have confounded results. It is reasonable to assume that some fraction of the larval population is exposed to potentially lethal effects with each passage.

In this paper a newly developed sampling tool and a preliminary analysis being used by the Huntington District to assess potential impacts are introduced. The objectives of this paper are to describe the typical abundance and distribution of larval fish (all species combined), estimate the extent to which physical forces potentially injurious to larvae surround a representative vessel, and quantitatively integrate these data to predict the vulnerability of larval fish to multiple passes.

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* The following is a preliminary examination of larval fish entrainment risk associated with existing navigation traffic on the Kanawha River, West Virginia. This analysis is intended merely to explore the potential for impacts and is subject to revision and/or expansion as may be required. Conclusions are based on the limited portion of the total database presently available, and as such are tentative.

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Methods

Sampling and larval fish distribution

The first objective is to describe a typical distribution of larvae relative to passing tows and their hydraulic effects. Previous Kanawha River larval fish distribution studies did not provide sufficient detail to make quantitative estimates of entrainment impacts, so additional spatial resolution was desired in the present study. In order to afford a finer level of control, a pair of modified Isaacs-Kidd trawls (MIK's) designed by the Huntington District were used for sampling (Figure 1). The MIK was designed to provide maximum depth control and sample size while minimizing gear evasion, gear-induced mortality, sample contamination, and inter-sample variation. Quantitative samples were collected in a 2- by 2- by 7-m, 500-micron Nitex mesh net. The net mouth was mounted in a lightweight aluminum frame which allowed the trawl to be remotely opened and closed, permitting discrete sampling at target depths. The trawl was suspended from an overhead beam mounted on a 3.65- by 3.00-m pontoon-style platform equipped with pulleys and winches. The central feature of the MIK platform is an open well through which the trawl is deployed and retrieved. It is also fitted with a bow extension plank and cleats to safely manage lines. The net frame could be precisely positioned at a fixed depth while linked to a separate anchor line

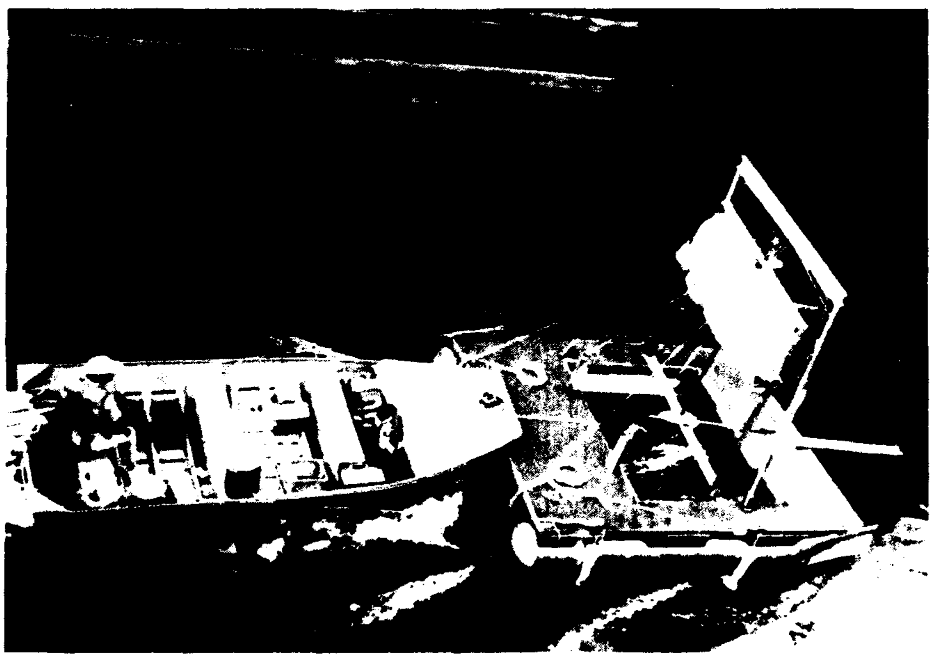

Figure 1. Modified Isaacs-Kidd trawl and deployment platform

from which hung a 45-kg steel weight. The combination of the anchor line and bow extension line maintained the trawl directly beneath the platform. Two sampling modes were possible; active and passive (Figure 2). During mobile sampling, the weight remains suspended just under the trawl, and a depth finder is used to maintain a clearance between the bottom of the trawl and the river bottom. Mobility is provided by fixing a utility boat powered with a

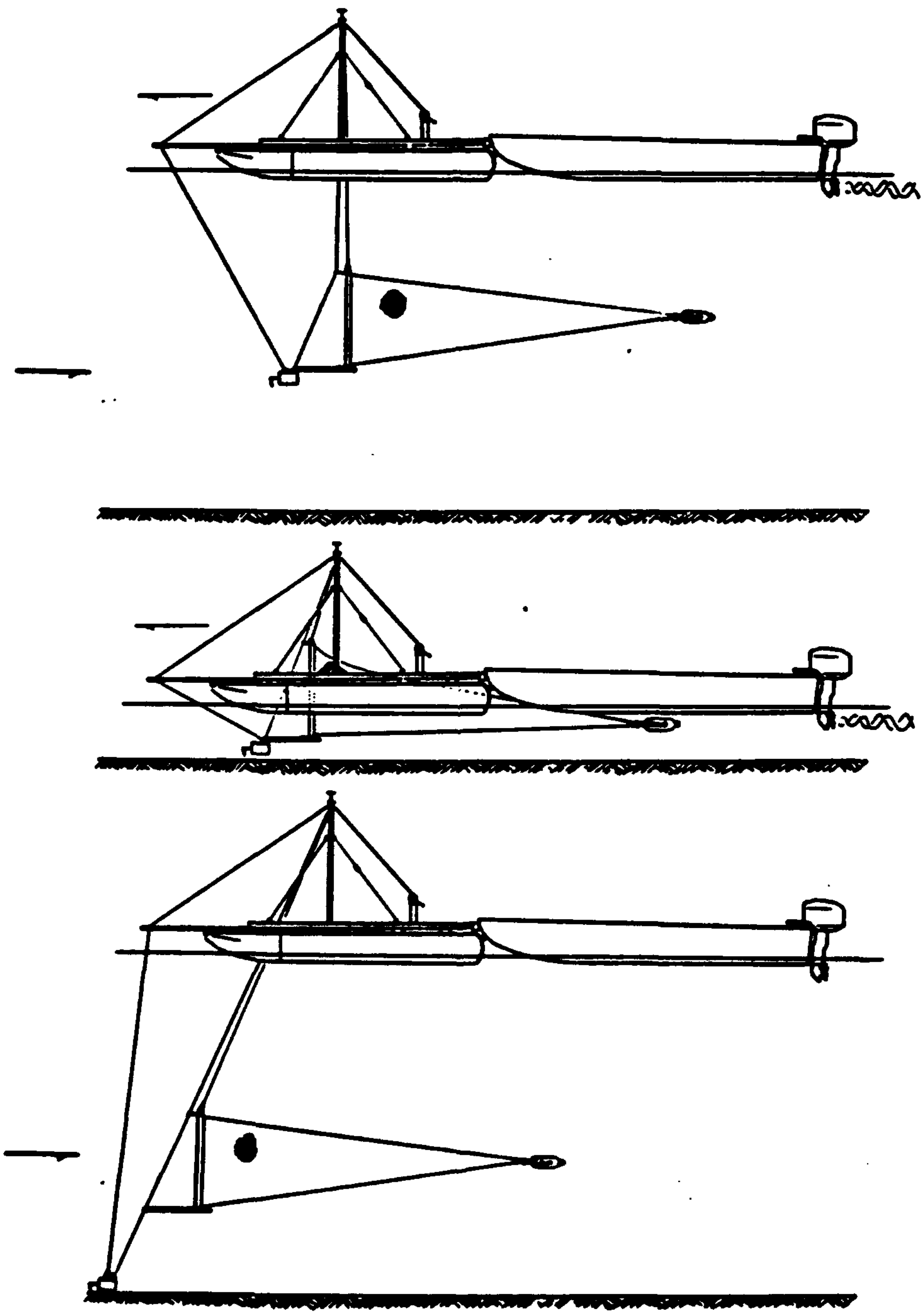

Figure 2. Illustration of sampling modes; active (deep), active (shallow), passive

25-hp* outboard motor to the stern of the MIK platform. A Marsh-McBierney Model 201 flowmeter probe positioned in the net mouth monitored water velocity (maintained at 0.5 fps during sampling).

A three-person crew (including one boat operator) is recommended for maximum safety and efficiency, although two could operate the gear if necessary. The MIK's were used to sample actively (under power) in depths which ranged from 0.6 to 9 m. At depths of less than 2 m, the trawl was only partially submerged. Sampling can also be done passively (while anchored in place) provided at least 0.2 fps of current is available. Active sampling was preferred because it allowed control over sample volumes under a variety of discharge conditions. Where ambient flow was less than 0.5 fps, net forward progress upstream was made, otherwise the MIK was allowed to slip downstream slowly (while facing upstream) in order to maintain the desired net mouth velocity. Sample duration was typically 5 min, which resulted in 6,340 cu ft of water passing through the net. Due to a large net mesh area to net mouth ratio (7:1) no back pressure was apparent at the low net mouth velocity used.

At the end of each sample period, the trawl was closed, retrieved from the water through the well, and the terminus of the net thoroughly washed down into the sample collection chamber. After sample volumes were appropriately reduced and any large debris removed, the sample was labeled and preserved in 10-percent Formalin solution for later sorting, enumeration, identification, and measurement in the laboratory.

In extreme nearshore habitats (less than 0.5 m), a 0.5- by 3.0-m 500-micron Nitex mesh larval seine was used to collect samples. By moving directly towards the shore very slowly along a measured distance, and noting depths at the start and end points, semi-quantitative samples were obtained. Use of the larval seine was restricted to gradually sloping banks free from snags and dense overhanging vegetation.

Transects spanning the entire river channel (approximately 600 ft wide) were established at three locations. The initial intent was to sample up to three depths at each of 10 stations on each transect. This regimen proved difficult to complete under all but the most favorable sampling conditions, however, and the sampling effort was reallocated after the first few trips. In the revised plan only that portion of a transect extending from midriver to

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* A table of factors for converting non-SI units of measurement to SI (metric) units is presented on page 7.

the left descending bank was sampled. The advantages of this plan included avoiding conflicts with existing traffic and crepuscular periods, and an increased level of resolution (eight stations could be used to span a half-transect of approximately 300 ft). Transects were chosen in the longest straight reaches available and it was assumed that larval fish distribution would exhibit bilateral symmetry in these reaches. Three consecutive samples were taken at each depth and location across a transect. Sampling was conducted biweekly from April through July and weekly during May and June when larvae reached peak abundances.

Estimation of the encounter zone

The second objective is to examine the flow patterns induced by passage of a vessel and to estimate the bounds of the encounter zone; that is, the portion of the channel cross section within which a larval fish would likely be exposed to potentially injurious forces during the course of vessel passage. This zone must be described by both the relative volume of the water mass under consideration and its pre-passage position. Estimates of these two components can then be integrated with larval distribution data to quantify exposure accompanying each passage. Due to the complexity of the hydraulics surrounding a vessel, this analysis used a conservative assumption concerning the extent of this zone. Three types of information were used to make a preliminary estimate - aerial observation of vessels, mathematical estimates of water volumes impelled by props (Kuo et al. 1988; Cobb 1988*), and scale modeling done by the US Army Engineer Waterways Experiment Station Hydraulics Laboratory under contract for the Corps of Engineers, Ohio River Division. In recognition of the uncertainty about this estimate, a sensitivity analysis was conducted to determine the behavior of the entrainment model.

Evaluating the risk of encounter

Each transect was divided into cells corresponding to the sampling stations. Within each cell and depth range the average density of larvae (for the three consecutive samples) estimated from field sampling on any given date was multiplied by the cell volume to yield the numbers of larvae present. The surface, middle, and bottom samples were pooled in this regard after scale model studies showed that, at least in shallow channels, the entire water column directly under a moving vessel is typically mixed. This effect was

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* Personal communication, 1988, Steve Cobb, Environmental Specialist, US Army Corps of Engineers, Lower Mississippi Valley Division, Vicksburg, MS.

particularly evident at the head of a loaded tow. Lacking detailed hydraulic information, it was assumed that larvae throughout the water column in the immediate vicinity of the vessel would be exposed to vessel effects.

The number of larvae throughout the water column within each cell was expressed as a cumulative percentage of the total number within the half transect, starting in midchannel and proceeding to the left descending bank. Assuming that vessels generally operate in or near midchannel, half the width of the encounter zone was translated through a graph of the cumulative distribution of larvae by cell to yield the fraction of larvae present in the cross section which are exposed (Figure 3).

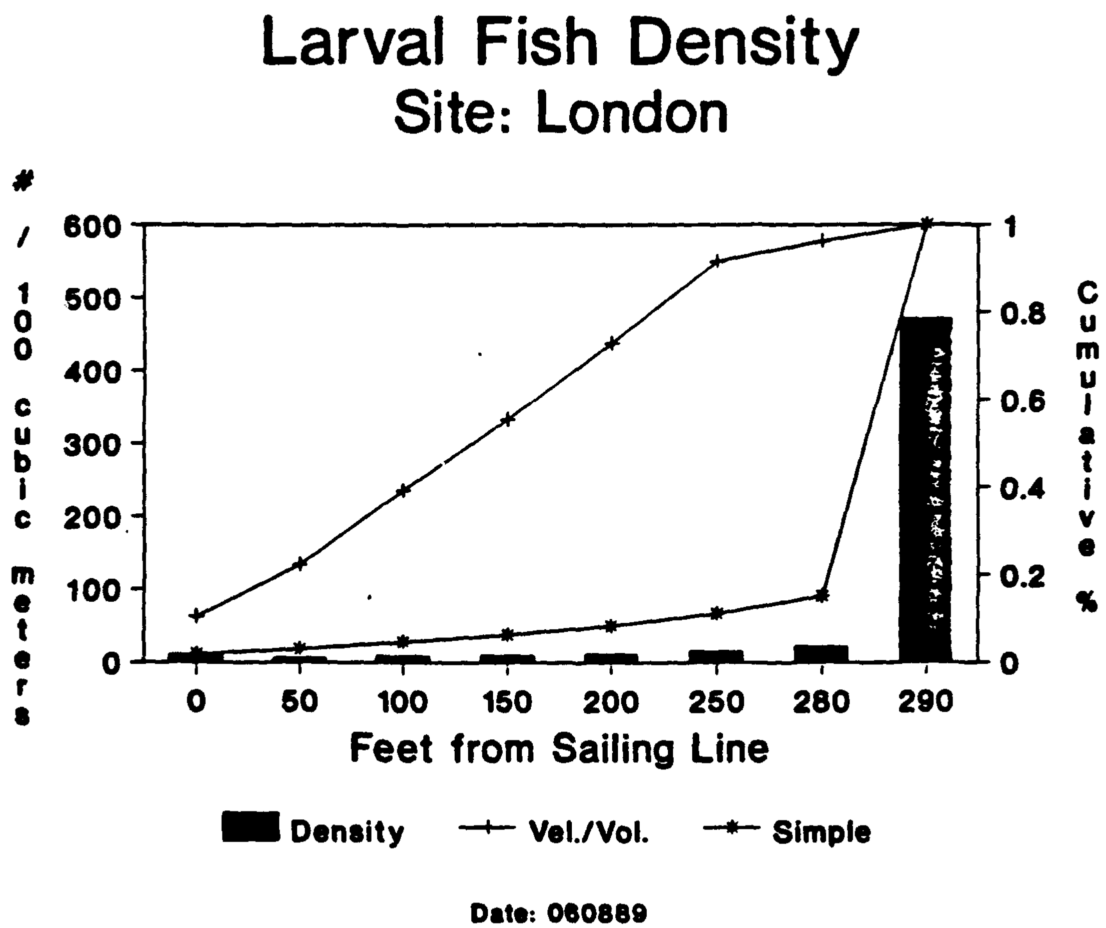

Figure 3. Density and distribution of larval fish on 8 June, 1989

To account for the river current and the upbound or downbound progress of the vessels, it was necessary to consider the cells as three-dimensional evaluation volumes through which both larvae and vessels transit (Figure 4). These volumes were bound by the width and depth of the cells, and the lengths assigned to each cell were given by the distance transited by the head of the

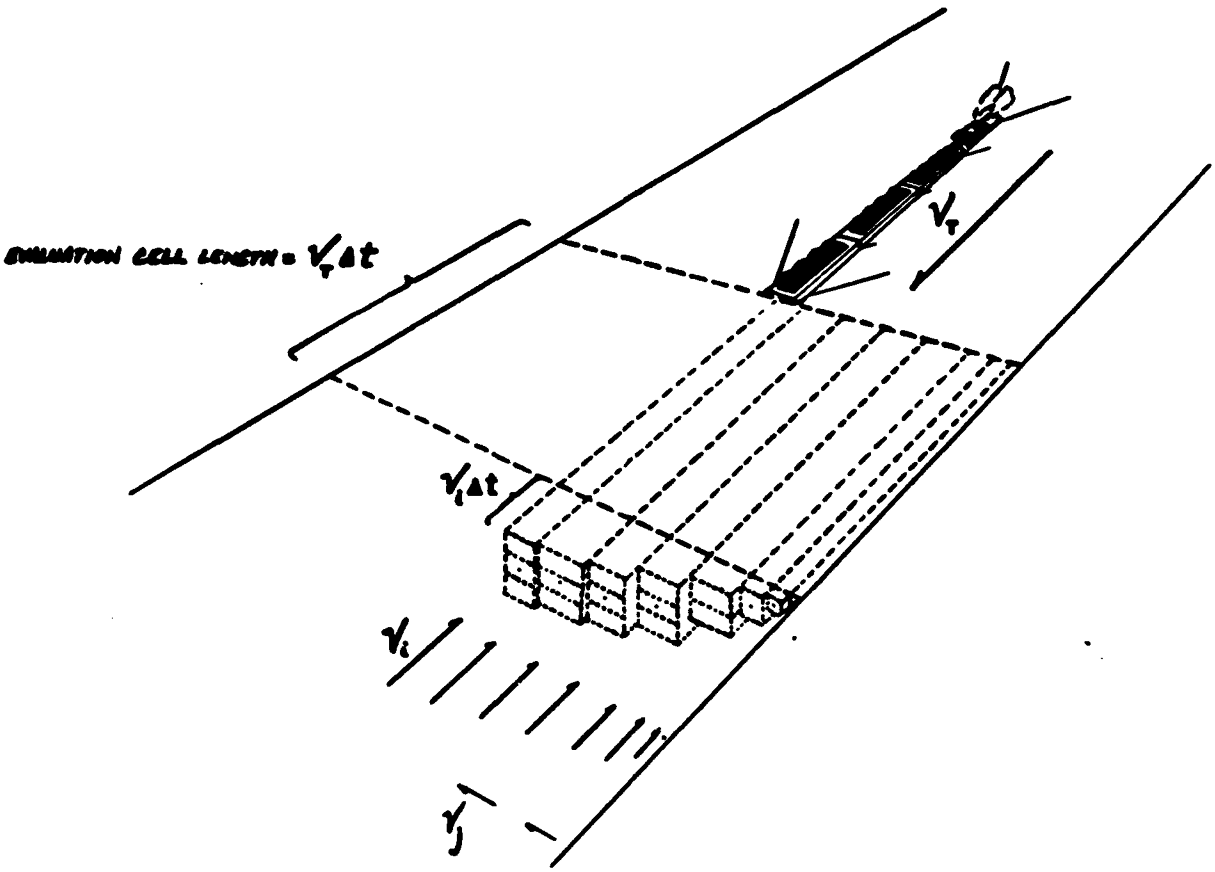

Figure 4. Illustration of evaluation volumes

vessel per unit of time, plus or minus the relatively small distance the water in the cell moves during this interval. For example, an upbound vessel with a ground speed of 6 mph covers a reach of 8.8 ft in 1 sec. If the water velocity in a cell is 0.5 fps, during 1 second the volume of water encountered at a midchannel location would be given by the cell width × cell depth × 9.3 ft. In the case of a downbound vessel, water velocity was subtracted from tow speed. These adjusted volumes were then multiplied by larval density in each cell prior to computing the cumulative distribution.

Given larval distribution, an estimate of the encounter zone and traffic frequencies, it is possible to compute the fraction of the larvae exposed over any number of passes. The cumulative effect of multiple passes was estimated by computing the probability of avoiding encounters, which may be given by:

$$X = [(1 - V) + V*(1 - E)^{t * d}] \qquad (1)$$

where X = undisturbed fraction of initial population

V = vulnerable portion of the population

E = fraction of fish population entrained per pass

t = tow passes per transect per day

d = days in evaluation period

This model assumes a redistribution of the vulnerable portion of the population after each pass; i.e., that larvae occupying the main channel mix and are equally vulnerable. A second portion which occupies the nearshore and channel borders remains isolated from direct encounters with traffic, regardless of the number of passes.

Results and Discussion

Sampling and larval fish distribution

Compared to more traditional sampling tools such as bongo nets, the MIK trawls performed well. Side-by-side comparisons were made between these two gears but the results are not yet available. One limitation was noted during mobile sampling tests. At net mouth velocities above 0.9 fps, considerable back pressure would develop and cause the trawl to swing back out from under the platform despite the weight and bow extension line, in which case depth could not be precisely controlled. At the target velocity of 0.5 fps, no such problem occurred. The intent of the gear was to approach fish slowly and thereby minimize alarm. Even adult fish that could easily outswim the gear were frequently captured, suggesting that the gradually approaching trawl did not prompt an evasive response.

The larval seine performed adequately, but some gear evasion was likely and only cover-free areas could be effectively sampled. If densities obtained by using this gear underestimate the true number of larvae present per unit volume of water along a typical bank, this would make the estimate of exposure more conservative. On average, larvae captured in the seine were larger than those taken with the MIK. Whether this is due to some difference in the gear or an actual size difference between habitats is unknown, but the latter is suspected if larvae use the nearshore zones as nursery areas.

On those few dates for which data are presently available, larval fish distributions demonstrated a consistent pattern. For example, at the London site on 8 June 1989, the density of larvae in the six open-water stations ranged from 6.11 to 15.66 per 100 m^3, and increased to 22.0 per 100 m^3 at the channel border station. In contrast, 471.34 larvae per 100 m^3 were found at the nearshore station (Figure 3).

If all cells had equal volumes and velocities, then the above data would suggest that the bulk of the larvae were well outside of the sailing line. However, the nearshore habitat is typically a shallow bench covered with very limited volumes of water. While it holds the highest densities, this water constitutes only about 0.001 of the available habitat. Consequently, the channel border and nearshore areas held only 0.084 of the larvae in this cross section at the time it was sampled. Thus a large fraction, 0.916 of the total larval population, occupied the main channel and was directly vulnerable to traffic on this date.

Velocities in the extreme nearshore habitat are commonly zero or nearly so at low-to-moderate flows and may be affected as much by shifting wind directions as by gravity, whereas velocities in the main channel are typically in the range of 0.5 - 1.5 fps. Thus the throughput (or turnover rate) in a mid-channel cell, in combination with the inherently greater volume of water found there, more than compensates for lower instantaneous densities of larvae (Figure 5). Vessel speed overshadowed the ambient velocity of the river by

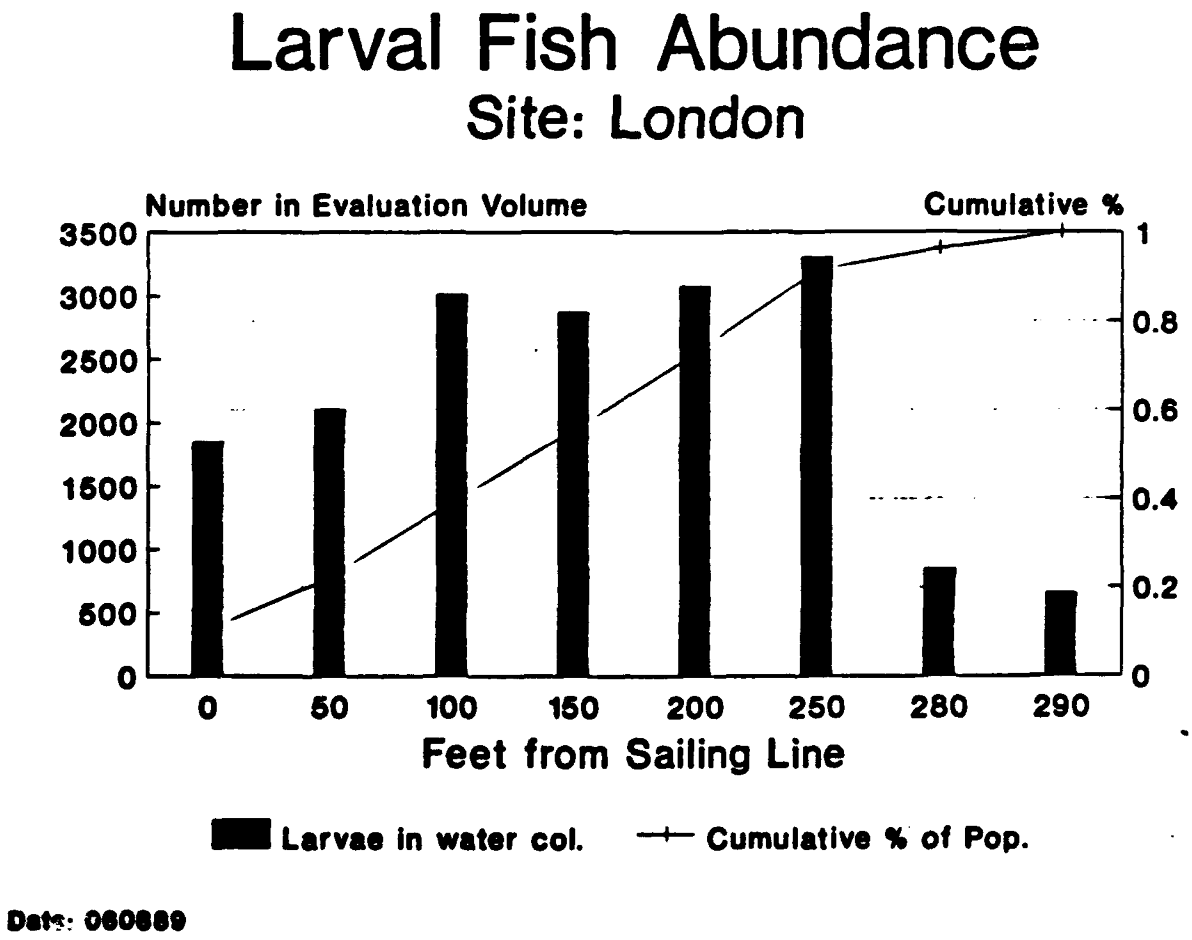

Figure 5. Abundance of fish larvae within evaluation volumes

about an order of magnitude, consequently river velocity did not greatly affect exposure. Vessel direction also had only a minor influence.

Earlier Kanawha River studies suggested that larval densities were commonly one to two orders of magnitude greater in shallow nearshore habitat than in the deeper, more open channel habitat (VPI&SU 1985). Embayments, where present, may support tenfold more larvae per unit volume than the adjacent nearshore habitats (Scott 1989). These observations are confirmed by numerous literature reports which suggest that, in general, larval fish occupying lotic systems prefer more shallow, quiescent areas. Higher densities and larger sizes of larvae in the nearshore habitat may be explained by several factors. Shallow water and relatively abundant cover may minimize predation risk. Reduced current velocities may minimize energy expenditures and displacement. Foraging for prey items may be more efficient in these areas as well. Daytime temperatures may be warmer, leading to higher growth rates. However, larvae may face a greater risk of de-watering or wave wash disturbance depending on the bank geometry in nearshore areas. Casual observation suggests that larvae remain just outside of the bank/water interface. This may offset the risk of drawdown and waves to some degree.

Estimation of the encounter zone

In earlier work done by the Huntington District attention was focused on the propeller jet, the effect of Kort nozzles versus open wheels, etc. However, only a small fraction of the average Kanawha River discharge is impelled through the propellers of the typical vessel found there (approximately 2.5 percent). Later work by the District and others demonstrated that high velocities are found not only in the propeller region, but at the head of the tow where sudden flow reversals may occur. Thus it would appear that propeller entrainment is only a subset of the entire field of disturbance to which larvae may be exposed.

Aerial observation as well as scale modeling suggest that the high velocities induced at the head of the tow occur over an area only slightly wider than the load itself and appear to extend throughout the water column under the vessel. For the sake of this analysis the encounter zone was assumed to be the entire water column 25 ft to either side of center of the tow's track; that is a 50-ft-wide swath. This estimate is considered conservative in that the present fleet employs 35-ft-wide jumbo barges in a 1 × 5 configuration. All larvae present in this zone are considered as having been exposed to potentially injurious forces. In reality a considerable

displacement flow envelopes the moving vessel, first being pushed out to the front, then off to the sides, and finally being drawn back in behind. Thus not all larvae initially occupying the sailing line pass directly under the vessel into the most turbulent regions. However some larvae located just off the sailing line may be drawn immediately behind the vessel and experience turbulence in a vessel's wake. Assuming the hydraulic conditions surrounding the vessel are less severe than those under it and in the props, this analysis utilizes a conservative estimate of the encounter volume.

<u>Evaluating cumulative risk of encounter</u>

The entrainment model was evaluated over a 30-day period under three sets of assumptions regarding the vulnerable portion of the population and the fraction of the vulnerable larvae occupying the encounter zone (Figure 6). All three cases assume a traffic frequency of 10 passes per day. Case I is a reference intended to reflect only the impact of that water being impelled by the props. Larvae are arbitrarily assumed to be uniformly distributed across

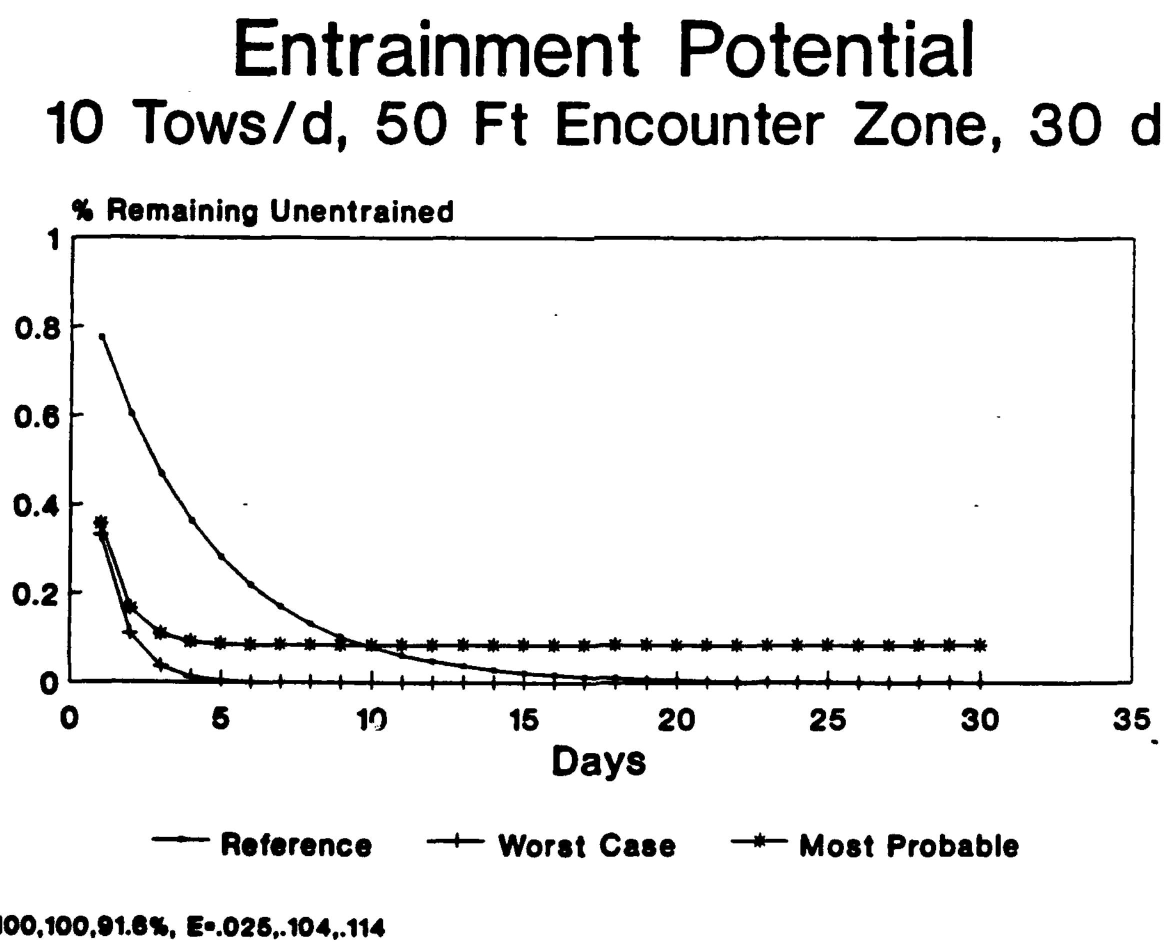

Figure 6. Fraction of population remaining unexposed over time

all habitats. Case II reflects a situation in which all larvae within the 50-ft-wide encounter zone centered on the sailing line are subject to impact. The 8 June 1989 distribution data were used and considered representative. Case III is similar to II except that only 91.6 percent of the larvae, the portion occupying the main channel, were vulnerable. Larvae in the nearshore zone and channel border were considered effectively separated from those in the channel and therefore immune to impact. In contrast, 100 percent of the larvae, including those on the margins of the main channel, were considered vulnerable in cases I and II.

The results of all three cases suggest that even at present levels of traffic, all or nearly all larvae are exposed to the effects of vessel passage (Figure 6). In the reference case (I) about 22 days are required before practically all larvae have been exposed. Only 6 days are required to expose most larvae in the worst case (II). In the "most likely" cases (III) nearly all vulnerable larvae are also exposed within about 6 days but 8.4 percent remain (unexposed) in the nearshore and main channel border habitats. The sensitivity analysis revealed that the model is much more sensitive to traffic frequency than to the size of the encounter zone. Most larvae occupying the main channel will be exposed in 2 weeks or less at current levels of traffic. As this analysis suggests that impacts are potentially significant, it will be expanded to incorporate the distribution of individual species and the relative effects of future tow traffic configurations and frequency.

Several interpretations can be drawn from this apparent high probability of exposure. One is that larval fish exposed to the vessel passage effects are injured or killed, and the reduction in recruitment potential severely impacts adult populations. However, fish populations have markedly improved or remained steady in the Kanawha River since the early 1970's, while traffic has grown over the same period. Therefore it would not appear that traffic limits adult populations. Improvements in water quality are generally cited as responsible for the resurgence of fish populations in the Kanawha and Ohio Rivers. Given suitable water quality, other factors such as inadequate prey densities at the end of endogenous feeding or scarcity of hiding cover for larval or juvenile stages appear to be more likely mechanisms to limit population sizes than are traffic effects.

Fecundity is typically quite high for river species, but it is doubtful if the apparent long-term recruitment trends would have occurred given high natural mortality in addition to the high vessel exposure rates estimated

here, provided the latter is presumed to result in mortality. An exceptional compensatory reserve would have to be assumed to account for improving fish populations during a period of increasing traffic.

This leads to the possibility that larvae exposed to traffic effects may simply not be impacted. While it may appear presumptuous to suggest that a lifestage commonly regarded as fragile withstands vessel encounters without harm, several characteristics may confer protection. In the earliest life stages a majority of larvae directly in the path of a tow are likely to slip around the vessel with the displacement flow. Small, weakly swimming larvae would flow with the water at low relative velocities and may enjoy the protection of thin boundary layers surrounding hull and prop blades. Susceptibility to shear is also minimized by short body length. For those drawn into the propeller region, small size minimizes the probability of direct strike. Rapid pressure changes in the vicinity of the propellers would not necessarily impact larvae which have not yet developed a swim bladder. The only physical disturbance to which larvae appear vulnerable is cavitation, but the propulsion units are designed and operated to minimize this. It is not unreasonable to question the commonly held assumption that larvae are easily damaged by vessel encounters. By the time they have grown sufficiently large that they would become susceptible to these hydraulic factors, they may have acquired sufficient evasive capability to avoid the regions surrounding the vessel most likely to cause damage.

The most reasonable interpretation is that some of the larvae which become entrained are damaged, while others are unharmed. In either case, however, main-channel habitat is normally of such low quality for growth and survival that most larvae found there would not recruit even in the absence of traffic and its presumed detrimental effects. The main channel of rivers similar to the Kanawha may well be inhospitable due to minimal cover, maximal exposure to predators, and relatively low prey densities. Foraging may be impaired due to natural turbulence. Suboptimal conditions in the main channel probably combine to delay growth, resulting in low survival. If this is the case the potential influence of vessel passage becomes a moot issue, excepting possible drawdown and wavewash effects upon more viable larvae occupying ecologically suitable nearshore habitats.

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A Strategy to Investigate the Environmental Effects of Commercial Navigation Traffic

Andrew C. Miller*

Background

A planner or engineer in a Corps of Engineers District, the US Fish and Wildlife Service, or a State agency must use an effective strategy to deal with commercial traffic effects. The strategy should not be an unalterable set of rules that apply in every circumstance, but a general guide that can be modified as necessary. The following approach to analyze the impacts of commercial navigation traffic has been developed as a result of conducting numerous studies on the effects of man's activities in navigable waterways.

Development of a Strategy

Preliminary evaluation

Before field work is initiated, an accurate description of the problem must be prepared. For a navigation project, this should include the predicted number and size of tows on a seasonal or annual basis. If the project consists of upgrading a port or loading facility, the size and number of tows, operation schedules, and the exact route that tows would use as they approach the facility are required. A map of the area should be prepared that would include important biotic and physical resources.

The purpose of the preliminary evaluation is to identify valuable resources such as aquatic macrophytes, mussel beds, gravel deposits, backwaters, or sloughs. Mainly qualitative information (species lists, presence/absence data, etc.) can be collected at this time. Results could indicate that additional study is warranted, or that biotic resources were not as valuable as once thought. Detailed studies may not be needed if valuable biotic resources are not present.

Qualitative biological and physical data can be collected with minimal equipment. Water velocity can be estimated with a stopwatch and float, depth

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can be measured with a string and weight. A petite Ponar dredge can be used to collect sediment samples for visual examination. Percentages of various grain sizes and amounts of organic matter can be estimated. At a later time these samples can be taken to the laboratory for more accurate analysis. Presence of mussels and insect larvae can be noted and density estimates can be made. Qualitative estimates of the effects of commercial vessel passage on velocity and suspended solids should be obtained. At a later time, the effects of vessel passage on suspended sediments or water velocity can be determined with specialized techniques and equipment (Bhowmik, Miller, and Payne 1990). Sites for physical and biological effects studies should be located to receive low, medium, and high effects of vessel passage. Distances can be estimated with an optical range finder or determined more accurately with electronic range finders. The number of vessels using the area can be noted and compared with records kept by Corps Lock and Dam operators.

Detailed investigation

If a detailed investigation is required, then representative sites should be chosen. Sites should span existing physical and biological conditions in the affected reach. They should exhibit the range of substrate conditions, water depths and velocities, and riparian vegetation. It is not possible to conduct a thorough investigation of an entire waterway; it is more realistic to study individual segments. Data from representative sites should be extrapolated to obtain information on the system.

The design for field work depends on the objectives of the study and the type of navigation project that is planned. It is useful to collect quantitative data on the biotic resource of interest at representative sites during several seasons or water levels for 1 to 2 years. This will provide good information on species diversity and richness, density of dominant taxa, life history patterns, evidence of mortality and recruitment. These biotic indices can be used to describe existing conditions and as a basis to make predictions (Miller and Payne 1988; Miller, Payne, and Ragland 1990; Miller, Payne, and Way 1989).

Indices of value that are used for habitat evaluation projects are (or at least should be) based upon empirically derived population level data. Quantitative results of field investigation such as species richness, diversity, or density, can always be converted to habitat suitability index scores. Physical data (substrate types, water velocity, chemical and physical conditions of water, etc.) should also be obtained.

Synthesis of Results

Predicting the environmental effects of commercial traffic

Three techniques can be used to predict the environmental effects of commercial navigation traffic:

a. The investigator can estimate impacts based upon information on existing biological conditions and an assessment of physical effects likely to be caused by the project (Bhowmik, Miller, and Payne 1990). Miller, Payne, and Ragland (1990) measured water vessel-induced changes in velocity over mussel beds and determined that the magnitude of change was typical of values usually found in large waterways. It appeared unlikely that measured vessel-induced velocities would negatively affect freshwater mussels or their habitat. On the other hand, if it is determined that vessel movement will create a large change in water velocity or suspended sediments close to aquatic plants or areas where fishes spawn, then negative effects could occur. In these cases the amount of valuable habitat must be known, as well as magnitude of the physical effect.

b. Results of laboratory experiments (Aldridge, Payne, and Miller 1986; Killgore, Miller, and Conley 1987; Payne and Miller 1987; Pearson et al. 1989) can be used to determine the influence of physical effects on specific organisms. However, naturally occurring populations may not respond in the same manner as laboratory-held organisms. Stress measured at the individual level may not be translated to the population level. The above-cited papers should be used mainly to gain an overall understanding of the effects of physical stress on aquatic organisms.

c. Numeric or simulation models can be used to predict physical effects. More information on these methods can be found in papers by Martin and Maynord, and Wilcox, in these Proceedings. This would alleviate the need to measure changes in water velocity or suspended solids as a result of traffic movement. Results from these models, when coupled with biological information, can be used to make estimates of impacts to the biota.

Interpretation

Results should be compared with data from other studies to interpret findings. For example, physical and biological data from sites that are similar with respect to all biotic and abiotic conditions except traffic levels can be contrasted. Results can be compared with data from previously conducted studies, although use of various sampling techniques can make this difficult. Field data also can be compared with results from numeric or

simulation models. This information can be used to verify models or suggest the need for additional field study.

Summary

Government personnel have used a variety of methods to study the effects of commercial navigation traffic. Information from laboratory studies can be used to predict navigation traffic effects. However, it is often difficult to compare results obtained from laboratory-held organisms with natural populations. Numeric or simulation models can be used to predict changes in water velocity or sediment concentrations following vessel passage. These results can be compared with information on tolerances of selected organisms to specific types of stress.

It is important to develop a strategy for designing and conducting a navigation effects study. Before the study is initiated, a pilot investigation should be completed. The purpose of the pilot investigation would be to gain qualitative information on aquatic resources and physical effects of vessel movement. Following interpretation of data from the preliminary study, a more detailed investigation can be initiated. The detailed investigation should include provisions for collecting quantitative biological and physical data during several seasons. Sample sites should be located to receive low, medium, and high effects of traffic. After quantitative data have been collected, the results of model studies or information from the technical literature can be use to predict effects. Aquatic resources along waterways are best protected if quantitative information is obtained to interpret trends. The effects of commercial navigation traffic, like the effects of any man-made impacts, can be studied and predicted using conventional methods.

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